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Testing of Screening Technologies for Detection of Chemical Warfare Agents in All Hazards Receipt Facilities

TECHNOLOGY EVALUATION REPORT

Office of Research and Development
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Technology Evaluation Report

Testing of Screening Technologies for Detection of Chemical Warfare Agents in All Hazards Receipt Facilities

By

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Notice

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Preface

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the nation's air, water, and land resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, the EPA's Office of Research and Development (ORD) provides data and science support that can be used to solve environmental problems and to build the scientific knowledge base needed to manage our ecological resources wisely, to understand how pollutants affect our health, and to prevent or reduce environmental risks.

In September 2002, EPA announced the formation of the National Homeland Security Research Center (NHSRC). The NHSRC is part of the ORD; it manages, coordinates, and supports a variety of research and technical assistance efforts. These efforts are designed to provide appropriate, affordable, effective, and validated technologies and methods for addressing risks posed by chemical, biological, and radiological terrorist attacks. Research focuses on enhancing our ability to detect, contain, and clean up in the event of such attacks.

NHSRC's team of world-renowned scientists and engineers is dedicated to understanding the terrorist threat, communicating the risks, and mitigating the results of attacks. Guided by the roadmap set forth in EPA's Strategic Plan for Homeland Security, NHSRC ensures rapid production and distribution of security-related products.

The NHSRC has created the Technology Testing and Evaluation Program (TTEP) in an effort to provide reliable information regarding the performance of homeland security-related technologies. TTEP provides independent, quality-assured performance information that is useful to decision makers in purchasing or applying the tested technologies. It provides potential users with unbiased, third-party information that can supplement vendor-provided information. Stakeholder involvement ensures that user needs and perspectives are incorporated into the test design so that useful performance information is produced for each of the tested technologies. The technology categories of interest include detection and monitoring, water treatment, air purification, decontamination, and computer modeling tools for use by those responsible for protecting buildings, drinking water supplies, and infrastructure and for decontaminating structures and the outdoor environment.

The evaluation reported herein was conducted by Battelle as part of the TTEP program. Information on NHSRC and TTEP can be found at http://www.epa.gov/ordnhsrc/index.htm.

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List of Acronyms

AEGL	Acute Exposure Guideline Level
AHRF	All Hazards Receipt Facilities
ATSDR	U.S. Agency for Toxic Substances and Disease Registry
CGI	combustible gas indicator
CH	hydrocarbon indication of commercial flame spectrophotometer
COC	chain of custody
CWA	chemical warfare agent
DHS	U.S. Department of Homeland Security
DI	deionized
DOD	U.S. Department of Defense
EC	electrochemical
EPA	U.S. Environmental Protection Agency
FBI	Federal Bureau of Investigation
FID	flame ionization detection
FPD	flame photometric detector
FSP	flame spectrophotometer
G/V	nerve agents
GB	sarin
GC	gas chromatography
HD	sulfur mustard
HD/HL	blister agents
HMRC	Hazardous Materials Research Center
HN/AC	blood agents
IMS	ion mobility spectrometer
IPA	isopropyl alcohol
L	liter
L/SA	arsenic compounds
LD_{50}	lethal dose to half the population
µg	microgram
µL	microliter
MF	mass flowmeter
MFC	mass flow controller
MSD	mass selective detection
MV	metering valve
NHSRC	National Homeland Security Research Center
PE	performance evaluation
PID	photoionization detector
ppb	part per billion
QA	quality assurance
QC	quality control
QMP	Quality Management Plan
RDT&E	research, development, test, and evaluation
RH	relative humidity

RSD	relative standard deviation
T	temperature
TIC	toxic industrial chemical
TSA	technical systems audit
TTEP	Technology Testing and Evaluation Program
UV	ultraviolet
VOC	volatile organic compound
VX	nerve agent designated VX
WMD	weapons of mass destruction

Executive Summary

This document is the final report on an evaluation of commercially available screening technologies that are designed to rapidly detect, and in some cases indicate the concentration of, chemical warfare agents (CWAs) in air, in liquid samples, and on surfaces. The technology evaluation described in this report was performed by Battelle under the direction of the U.S. Environmental Protection Agency's (EPA) National Homeland Security Research Center (NHSRC) through the Technology Testing and Evaluation Program (TTEP). The technologies evaluated were identified as possible candidates for use in EPA's All Hazards Receipt Facilities (AHRF).

The EPA, U.S. Department of Homeland Security (DHS), and U.S. Department of Defense (DOD) have teamed to develop, construct, and implement the AHRF for prescreening unknown and potentially hazardous samples collected during suspected terrorist events. The AHRF are intended for screening of samples for chemical, explosive, and radiological hazards, to protect laboratory workers from injury and facilities from contamination, and to ensure the integrity of collected samples. These facilities are not intended to provide detailed or quantitative analytical results, but instead to provide initial screening of samples prior to full laboratory analysis, for the safety of laboratory personnel. Screening technologies used in the AHRF are intended to be rapid and qualitative, and may be of relatively low cost and "low tech" in design, but must provide accurate identification of hazardous samples.

The procedures and target CWAs used in this evaluation were chosen to represent likely conditions of use in the AHRF. In performing this technology evaluation, Battelle followed the procedures specified in a peer-reviewed test/QA plan established prior to the start of the evaluation, and complied with all the quality requirements in the Quality Management Plan for the TTEP program. The screening technologies tested ranged from simple test papers, kits, and color indicating tubes to hand-held electronic detectors based on ion mobility spectrometry (IMS), photo ionization detection (PID), electrochemical (EC) sensors, and flame spectrophotometry (FSP). Each technology was tested with CWAs and sample matrices for which it was designed. The screening technologies were challenged with the CWAs sarin (designated GB) and sulfur mustard (HD) in air at concentrations that would be seriously hazardous to personnel within a few minutes of exposure. Those vapor phase challenges were delivered at base conditions, i.e., room temperature and normal (50%) relative humidity (RH), both with and without a volatile exhaust hydrocarbon mixture added as an interferent, and at relatively high (30°C, 80% RH) and low (10°C, 20% RH) temperature and humidity conditions without the interferent. Liquid samples were made up with GB, HD, and VX, in both isopropyl alcohol (IPA) and water, at concentrations that would be hazardous upon physical contact with the water sample. Surface samples consisted of glass coupons dosed with VX at one-tenth the LD_{50} surface loading.

Regarding accuracy for screening vapor phase CWAs, five of the 10 technologies tested with GB correctly detected that agent, and four of the eight technologies tested with HD correctly detected that agent. The five screening technologies that accurately detected GB vapor did so even in the presence of the hydrocarbon interferent mixture, and at low and high temperature and RH

conditions. Of the four screening technologies that accurately detected HD vapor at the base test conditions, only two also did so at low and high temperature/RH conditions and with the interferent mixture present.

Accurate detection of CWAs in water samples was limited to four technologies (out of 11 tested) that were able to detect one or more CWAs. Two commercial color ticket technologies which use acetylcholinesterase inhibition as their detection principle correctly detected GB and VX in water (both without and with diesel fuel added as an interferent). The FSP instrument correctly detected GB in all samples, but did not respond to VX, and responded strongly to HD only when the diesel fuel interferent was also present. The various test papers (M8, M9, and 3-way) were generally not able to detect the CWAs in water at the challenge concentrations used in this evaluation.

Accuracy in detecting VX on test coupon surfaces was high, with all nine of the tested technologies correctly detecting VX even at high and low temperature and RH conditions, and with diesel fuel present on the surface as an interferent. Among those nine technologies were various test papers (M8, M9, and 3-way).

False positive responses were rare in testing with GB and HD vapor, occurring in only a few test conditions with only four of the 10 technologies tested. None of the tested technologies produced any false positive responses in testing with CWAs in water samples. In surface testing, the FSP gave two false positive responses when sampling blank coupons at the High temperature and RH condition. Those responses appeared to be a memory effect after strong positive responses were observed to the challenge (spiked) coupons at that condition.

False negatives were observed with several screening technologies in both the CWA vapor and liquid sample testing, primarily in the inability of the technologies to detect a CWA under the base test conditions. False negatives were also observed in only a few cases when testing with an interferent, or at low or high temperature/RH conditions. Those occurrences are described below. Notably, a few technologies showed false negative responses in CWA vapor testing even though the GB or HD challenge concentration was equal to or higher than the detection limit of the technology indicated by the vendor.

Most screening technologies showed no effect from the interferents used in the evaluation. In vapor testing the hydrocarbon interferent mixture did reduce the ability of some technologies to detect HD. Diesel fuel added as an interferent in water had a negative impact on one technology's ability to detect the CWAs, a positive impact on another, and no effect on the rest. Temperature and RH effects were also minimal.

The speed and simplicity of the vapor screening process varied widely among the tested technologies, and ease of use was not necessarily correlated with accuracy in CWA screening. The vapor detection technologies based on color indicating tubes were simple to use in principle, but differed in the time and difficulty of obtaining the sample. With such technologies, the number of manual pump strokes required to draw in the air sample ranged widely, and the manual effort needed for those technologies requiring multiple pump strokes was sometimes excessive. One technology used an electric air sampling pump that greatly reduced the physical effort needed, but still required a few minutes to draw the required volume. Use of color indicating tubes that require the minimum sample volume would seem preferable for use in the AHRF, and use of an electrical sampling pump might be helpful even then, if large numbers of samples are to be screened. The three real-time analyzers tested (a PID, an FSP, and an IMS) provided easy and rapid sample screening for CWA vapors, though with widely differing levels of accuracy in CWA detection. A technology called the HazMat Smart Strip was the simplest technology to use, requiring only removal of a protective film to expose the indicating patches on the card, but this technology was not successful as a screening tool in this evaluation.

In terms of the speed and simplicity of liquid and surface sample screening, the M8, M9, and 3-way indicating papers were especially easy to use. The two acetylcholinesterase color tickets were also relatively simple, and the screening of water and surface samples with the FSP was also relatively rapid, because of the simplicity of using that detector's "scraper" attachment and desorbing these samples into the instrument inlet.

The applicability of a technology to screen for multiple CWAs at once is an important component of the speed of analysis. Technologies using multiple color indicating tubes at once can provide this capability. On the opposite end of the complexity spectrum, the FSP provided multi-CWA capability, and was applicable to vapor, liquid, and surface samples.

The initial cost of the screening technologies varied substantially, with technology purchase costs ranging from a few hundred to a few thousand dollars for all but two of the tested technologies. The two exceptions were the FSP at a discounted cost of nearly $16,000, and the IMS at a cost of $10,000. However, when considering long-term use of the technologies in the AHRF, the per-sample CWA screening costs were similar across many different technologies, i.e., typically ranging from $4 to $20 per sample. The simple test papers were the least expensive, with screening costs estimated at less than $0.50 per sample.

1.0 Introduction

This document is the final report on an evaluation of commercially available screening technologies that are designed to detect the presence, and in some cases indicate the concentration, of chemical warfare agents (CWAs) in air, on surfaces, or in liquid samples. The technology evaluations described in this report were performed by Battelle under the direction of the U.S. Environmental Protection Agency's (EPA) National Homeland Security Research Center (NHSRC) through the Technology Testing and Evaluation Program (TTEP) (Contract GS-23F-0011L-3), and specifically under Task Order 1119 of the TTEP program. The technologies evaluated were identified as possible candidates for use in EPA's All Hazards Receipt Facilities (AHRF), and the testing was designed to evaluate their performance relative to the needs of the AHRF as currently defined in the draft sample screening protocol developed for the AHRF.[1, 2]

The EPA, U.S. Department of Homeland Security (DHS), and U.S. Department of Defense (DOD) have combined efforts to develop, construct, and implement AHRF capabilities for prescreening unknown and potentially hazardous samples collected during suspected terrorist events. AHRF development was initiated in response to requests from states and federal agencies, particularly public health laboratories, for standardized guidance on screening samples to protect laboratory staff and ensure sample integrity and the validity of analytical results. The AHRF are intended for in-process screening of unknown samples for chemical, explosive, and radiological hazards to protect laboratory workers and facilities from contamination and injury. The AHRF are intended to serve as a front end assessment that can be used on an "as needed" basis. These facilities are not intended to provide detailed or quantitative analytical results, but instead to provide initial screening of samples prior to full laboratory analysis, for the safety of all laboratory personnel. Screening technologies used in the AHRF are intended to be rapid and qualitative, and may be relatively low cost and "low tech" in design, but must ensure meaningful qualitative results.

This report presents the results of evaluation of commercially available screening devices for rapid detection of CWAs in samples and on sample containers entering an AHRF. A separate report[3] presents the results of testing such technologies for detection of toxic industrial chemicals (TICs). The procedures, target chemicals, and sample types used in this evaluation were chosen to represent conditions of use likely to be present in the AHRF.[1, 2] Figure 1-1 is excerpted from the AHRF Draft Protocol,[1] and illustrates the sample screening process to be implemented through the AHRF. As this figure shows, screening of an incoming sample or sample container for chemical contamination occurs in multiple steps of the process, and may use multiple screening technologies.

In performing this technology evaluation, Battelle followed the procedures specified in a peer-reviewed test/quality assurance (QA) plan established prior to the start of the evaluation,[4] and complied with all the quality requirements in the Quality Management Plan (QMP)[5] for the TTEP program.

Sample Receipt and Transport Container Screen: Outside AHRF

- Establish/Continue chain of custody
- Review corresponding documentation and interview the delivery technician
- Visual inspect transport container (check for explosive device, radiation and unusual liquid or powder – If present, collect sample, mitigate hazard and contact appropriate authorities)
- Document observations, complete Sample Receipt Forms, and assign tracking identification
- Carry out a threat assessment and develop a screening plan

Primary Sample Container Screen: Inside Fume Hood

- Screen headspace for CWAs with ion mobility spectrometer (IMS) or flame spectrophotometer (FSP)
- Remove contents from transport container and secondary container (if necessary)
- Visually inspect and screen primary sample container for radioactivity (surface screen), explosives (colorimetric), and CWA (colorimetric)
- If hazards are indicated, collect exterior wipe sample, mitigate hazards indicated via decontamination of exterior surfaces or shielding, and contact appropriate authorities
- Document observations and results on AHRF Screening Results Form
- Assess need to continue screening process and ability to transfer to glove box

Primary Sample Screen: Inside Glove Box and Biosafety Cabinet

- Transfer primary sample container to glove box
- Open primary container and screen for VOCs (photoionization detector) and combustible gases (combustible gas indicator)
- Screen primary sample for radiation (surface scan)
- If sufficient amount of sample is present, split sample and continue screening process
- Remove small portion of the sample and transfer into the biosafety cabinet. Conduct the optional screen using IMS and/or FSP. Conduct thermal susceptibility test to determine if explosive materials are present.
- Perform water solubility and reactivity test
- Perform DB-3 dye test for alkylating agents (colorimetric)
- Perform pH and starch iodide test (colorimetric)
- Perform nerve agent test (colorimetric)
- Perform the additional chemical screening as needed (colorimetric)
- Document observation and results on AHRF Screening Results Form

Document Results

- Complete and verify AHRF Screening Results Forms
- Compile all forms into a single AHRF Screening Report
- Contact sampling agency, appropriate local authorities, the local laboratory director, and the FBI WMD coordinator
- Prepare sub sample and primary sample for delivery to the designated laboratory and/or sampling authority
- Transfer to the biosafety cabinet to await transfer

Figure 1-1. Summary of All Hazards Receipt Facility Sample Screening Process

2.0 Technologies Tested

The screening technologies tested were identified based on a review of commercially available detection devices for the CWAs and TICs of interest. That review was wide ranging, in that information on detection devices was initially obtained without concern about the applicability of each device to the AHRF sample screening process. Screening technologies were then selected for testing based on criteria specific to the intended use in the AHRF, i.e.:

- Applicability to multiple target CWAs and TICs
- Applicability as a qualitative screening tool
- Applicability to multiple sample types (vapor, liquid, surface)
- Speed and simplicity of use
- Cost of use and consumables

The technologies selected for testing were predominantly relatively inexpensive, simple test kits, color tubes, and test strips, but also included a few hand-held electronic instruments employing various detection principles. The reason for inclusion of the latter technologies was their applicability to a wide range of CWAs and/or TICs, and their rapid response, which made them attractive as potential screening devices despite their relatively high initial cost.

Table 2-1 lists the vendor and name of each technology selected for testing with CWAs in this program, the detection principle, and the CWAs for which each technology was tested in the surface, liquid, and vapor sample matrices. As Table 2-1 shows, the CWAs sarin (designated GB), sulfur mustard (HD), and VX were used in this testing. Brief descriptions of each CWA screening technology are provided below.

Agentase CAD Kit. This technology is designed to detect CWAs on surfaces, and consists of a reservoir of reagent within a plastic pen-shaped container having a soft porous tip. Bending the container breaks the reagent reservoir and soaks the porous tip. The surface to be tested is then wiped with the porous tip, and the appearance of a color indicates the presence of agent. Only Agentase pens designed to detect VX were tested in this project, because the low volatility of that agent makes it the most likely agent to be present on sample surfaces entering the AHRF. Appearance of a pink color in the porous tip indicated the presence of VX. http://www.agentase.com/cad-kit.php

Anachemia C2. This kit includes three distinct technologies for CWA detection, including 3-way paper, a color ticket, and color indicating tubes. The 3-way paper indicates the presence of CWAs by means of a color change, and was tested with liquid and surface samples. The color ticket detects nerve agents based on acetylcholinesterase inhibition, and was tested for detection of GB in the vapor phase. With this technology, a reagent pad must first be moistened with clean water, and then exposed to the test atmosphere by means of a small pump. After exposure, pressing the detector body into the holder contacts a test paper with the reagent pad. A white color indicates the presence of agent, and the appearance of blue color indicates no agent

Table 2-1. Technologies Tested for CWA Screening

			Sample Type					
Screening Technology			Surface	Liquid			Vapor	
Vendor	Name	Detection Principle	VX	Sarin (GB)	VX	Sulfur mustard (HD)	Sarin (GB)	Sulfur mustard (HD)
Agentase	CAD Kit	color indicating pen	X					
Anachemia	C2	3-way paper	X	X	X	X		
		color ticket					X	
		color tubes						X
	CM256A1	3-way paper	X	X	X	X		
		multifunction card					X	X
Draeger	Civil Defense Kit	color tubes					X	X
MSA	CWA Sampler Kit	color tubes					X	X
Nextteq	Civil Defense Kit	M8 paper	X	X	X	X		
		M9 paper	X	X	X	X		
		3-way paper	X	X	X	X		
		color tubes					X	X
Proengin	AP2C	Flame spectrometer	X	X	X	X	X	X
RAE Systems	MultiRAE Plus	PID					X	X
Safety Solutions	HazMat Smart Strip	multi-function card		X	X		X	
	HazMat Smart M8	M8 paper	X	X	X	X		
Severn Trent	Eclox Pesticide Strip	color ticket		X	X			
Smiths Det'n	APD2000	ion mobility					X	X
Truetech	M272 Water Kit	color ticket		X	X			
	M18A3	M8 paper	X	X	X	X		
		color ticket					X	

present. The color indicating tube technology works by drawing sample air through a bed of solid reagent in a glass tube; a color change in the reagent indicates the presence of the agent. This technology was tested for detection of HD in the vapor phase, and includes a hand pump for drawing the required sample volume through one tube at a time. With this technology ten compressions of the pump provide the required sample volume. http://www.anachemia.com/defequip/product.html

Anachemia CM256A1. This kit includes two CWA screening technologies. One was 3-way paper, which indicates the presence of CWAs by means of a color change, and which was tested with liquid and surface samples. The second technology is a multifunction card that employs reagents placed in selected locations on the card, with manual manipulation of portions of the card to initiate reactions, produce heat, and observe color changes in the reagents. Each card can indicate the presence of vapor phase TICs and CWAs by the performance of a series of about 15 sequential steps and manipulations. http://www.anachemia.com/defequip/product.html

Draeger Civil Defense Kit. This technology uses a hand pump to draw air through five different color indicating tubes simultaneously, with each tube providing an indication of one vapor phase TIC or CWA, including GB and HD. All five tubes must be in place in the five-port sampling holder for proper sampling to occur. Fifty compressions of the hand pump provide the required sample volumes to all five tubes. http://www.ffpsafety.com/draeger/tube_sets_sub.htm

MSA Single CWA Sampler Kit. This device also uses color indicating tubes to detect GB and HD, with a hand pump to draw sample air through a single indicating tube at a time. Thirty compressions of the hand pump provide the required sample volume. http://www.msanorthamerica.com/catalog/product679.html

Nextteq Civil Defense Kit. This technology incorporates four different CWA screening approaches. Three of those approaches are color indicating papers, i.e., M8, M9, and 3-way papers, which were tested with CWAs in liquid samples and on surfaces. The fourth approach uses an electric pump (or optional hand pump) to draw air through five different color indicating tubes simultaneously, with each tube providing an indication of one vapor phase TIC or CWA, including GB and HD. All five tubes must be in place in the five-port sampling holder for proper sampling to occur. The electric pump is preset to draw the required 3.5 L of air through the five sampling tubes within a sampling period of 3.5 minutes. http://www.nextteq.com/Products.aspx?category=3&subcat=16

Proengin AP2C. The Proengin AP2C is a hand-held flame spectrophotometer (FSP) that detects characteristic emissions from hazardous chemicals as they are consumed in a flame. The device burns hydrogen, supplied from a compact low-pressure cylinder inside the instrument, with sample air drawn continuously by an internal pump. Detection of a target chemical triggers an alarm from the AP2C, and the instrument provides identification and semi-quantitative readings for the detected chemical. Such readings take the form of series of five bars that successively turn orange depending on the intensity of response, with separate sets of bars for blister agents (HD/HL), blood agents (HN/AC), nerve agents (G/V), and arsenic compounds (L/SA). The AP2C also provides a general indication of the presence of hydrocarbon compounds by means of a single bar "CH" display. A "scraper" attachment for the device allows liquid samples (either neat samples or solutions) to be picked up on disposable scraper tips and vaporized into the inlet of the AP2C by means of a heating circuit in the detachable scraper handle. http://www.proengin.com/fp_ap2c.htm

RAE Systems MultiRAE Plus. The MultiRAE Plus is a hand-held photoionization detector (PID) for volatile organics in air that also can incorporate electrochemical sensors for oxygen, explosive gases, and selected TICs. In the PID, an ultraviolet (UV) light source causes ionization of those molecules in the sample air stream that have an ionization potential less than the energy of the UV light. It should be noted that the PID principle of the MultiRAE Plus is not necessarily expected to respond to the CWAs, but because the MultiRAE Plus is promoted for use as a general toxic compound detector, it was tested with CWA vapors. The MultiRAE Plus unit tested was also equipped with an electrochemical sensor for the TIC hydrogen sulfide (H_2S). http://www.raesystems.com/products/multi_gas

Safety Solutions HazMat Smart Strip. The HazMat Smart Strip is a card that may be attached to a surface, such as a person's clothing, by means of its adhesive backing. The front surface of the card has eight squares of colorimetric reagents, that produce qualitative indications of the presence of several respective contaminants, including chlorine, acids or caustics (pH indication), fluoride, nerve agents, oxidizers, arsenic, hydrogen sulfide, and cyanide. Removal of a protective film exposes the reagent squares and allows any indicating reactions to take place. The Smart Strip was tested with liquid and vapor phase samples. http://www.smart-strip.com/

Safety Solutions HazMat Smart M8. The HazMat Smart M8 is a badge that may be clipped to a person's clothes, and consists of a piece of indicating paper in a cardboard frame. The Smart M8 badge was tested with liquid and surface samples. http://www.smart-strip.com/order.htm

Severn Trent Eclox Pesticide Strip. This CWA screening technology is a nerve agent detection ticket based on acetylcholinesterase inhibition, designed for water sample screening. The technology uses two reagent pads under a foil protective covering. To use the ticket, the foil covering is removed, and one of the reagent pads is wetted with the sample and then pressed against the second reagent pad. A resulting white color on the first pad is the indication of the presence of nerve agent; a blue color indicates no agent is present. The Eclox Pesticide Strips are part of the Eclox portable field water quality assessment system, but may be purchased separately.
http://www.severntrentservices.com/instrumentation_products/portable_water_assessment/index.html
http://www.epa.gov/etv/verifications/vcenter1-38.html

Smiths Detection APD2000. This technology is a hand-held detector for vapor phase CWAs based on the principle of ion mobility spectrometry (IMS). In this instrument, molecules in the sampled air are ionized by a small radioactive source, and the ions are then separated by their drift in air at atmospheric pressure in an electric field inside the instrument. The time/intensity pattern of the ion signal is used to identify the target chemicals. This instrument is battery powered, and draws its sample air using an internal pump. Displays include a relative intensity indication, identification of the type of CWA detected (i.e., nerve, blister), and visible and audible alarms. A confidence check sample, consisting of a source of simulant vapor, was supplied with the APD2000. This source was used to confirm proper performance of the detector at the start of each day of testing, and this check was repeated as needed during performance of testing. http://www.sensir.com/Smiths/APD2000/APD200.htm

Truetech M272 Water Kit. The CWA screening technology in this kit is a nerve agent detection ticket based on acetylcholinesterase inhibition, that is similar to the Severn Trent Eclox Pesticide Strip in that it uses two reagent pads under a foil protective covering. This ticket is intended for screening water samples. To use the ticket, the foil covering is removed, and one of the reagent pads is wetted with the sample and then pressed against the second reagent pad. A resulting white color on the first pad is the indication of the presence of nerve agent; a blue color indicates no agent is present. http://www.tradewaysusa.com/eng/products/if_detection.htm

Truetech M18A3. This kit includes two CWA screening technologies, namely M8 paper and a color ticket. The M8 paper is applicable to CWAs in liquid samples and on surfaces. The color ticket is similar to that in the Anachemia C2 kit. It is based on acetylcholinesterase inhibition, and is intended for detection of nerve agents in the vapor phase. With this ticket the presence of CWAs is indicated by a white color on the indicating pad after the conclusion of the indicating reaction. http://www.tradewaysusa.com/eng/products/if_detection.htm

3.0 Testing Procedures

3.1 Performance Parameters

The key performance parameters evaluated for the CWA screening technologies were:

- Accuracy of identifying hazardous samples
- False positive/false negative rates
- Analysis time

In addition, technologies providing more than a simple yes/no response were evaluated for the following performance parameter, using the responses displayed by these devices:

- Repeatability

These performance parameters are defined below, and general test procedures are described in Section 3.2. The CWA evaluation was performed according to the requirements of the test/QA plan[4] and the TTEP QMP.[5]

In addition to these key performance parameters, operational characteristics of the screening technologies were evaluated based on operator observations. These operational characteristics included:

- Ease of use
- Data output
- Cost

3.1.1 Accuracy of Hazard Identification

Accuracy is the ability of a screening technology to identify hazardous samples, so that they can be properly handled to minimize risk to laboratory personnel. Accuracy was measured in terms of the percentage of prepared hazardous samples that were correctly identified as hazardous by the screening technology in question.

3.1.2 False Positive/False Negative Rates

A false positive screening result occurs when a technology incorrectly identifies a safe sample as being hazardous. A false negative screening result occurs when a technology incorrectly identifies a hazardous sample as being safe. Responses that identified samples as hazardous when they contained none of the target CWAs were denoted as false positives. The absence of a hazard indication with a sample containing a target CWA was denoted as a false negative.

3.1.3 Analysis Time

Analysis time is the time needed to screen a single sample or group of samples with an individual technology. Analysis time is driven by the response time of a technology in indicating a hazard upon presentation of a sample, and takes different forms for different screening technologies. For continuous monitors (e.g., the Smiths Detection APD2000, or Proengin AP2C) analysis time is dependent on instrument response and recovery time. For colorimetric papers the speed of analysis is limited by the color development time after the start of exposure, whereas for colorimetric gas sampling tubes, the time required to draw the required volume of sample gas through the tube is likely to be the limiting factor. For all technologies tested, the appropriate response time was noted to provide a consistent comparison of analysis times.

3.1.4 Repeatability

The responses provided by some sample screening instruments include quantitative readings. Such readings were recorded and the repeatability of such indications was calculated in terms of a percent relative standard deviation (% RSD) of the triplicate challenges at different test conditions.

3.1.5 Operational Characteristics

Ease of use was assessed by operator observations, with particular attention to the conditions of use during screening. This assessment was done in the course of evaluating other performance parameters with VWAs, i.e., no additional test procedures were designed specifically to address only the operational characteristics.

For each screening technology, the type of indication or data output was noted (e.g., color change, intensity of color change, low/med/high indication, audio or visual alarm, quantitative measure of concentration, etc.), and the clarity of the indication was assessed.

Costs for each technology were assessed based on the purchase and operational costs of the technologies as tested. This technology evaluation was not of sufficient duration to test long-term maintenance or operational costs of the technologies. Estimates for key maintenance items were requested from the vendors as necessary.

3.2 Test Procedures

All testing with CWAs was conducted at Battelle's Hazardous Materials Research Center (HMRC), in West Jefferson, Ohio. The HMRC is an ISO 9001-certified facility that provides a broad range of materials testing, system and component evaluation, research and development, and analytical chemistry services requiring the safe use and storage of highly toxic substances. Battelle operates the HMRC in compliance with all applicable federal, state, and local laws and regulations, and the HMRC is authorized to store and use CWAs under a bailment agreement with the U.S. Army.

3.2.1 Vapor Phase Testing

Screening technologies were evaluated based on their ability to respond to CWAs in the vapor phase, using a test apparatus represented schematically in Figure 3-1. The test system consists of a vapor generation system, a Nafion® humidifier, two challenge plenums, a clean air plenum, metering valves (MVs), RH sensors, thermocouples, and mass flow meters (MFs) and controllers (MFCs). Only one of the two challenge plenums was used in this evaluation. The challenge vapor concentrations of GB and HD were generated by diluting vapors evolved from a diffusion cell containing the neat agent, and maintained at a constant temperature. Testing was conducted with one CWA at a time, and on one screening technology at a time, using this apparatus. As illustrated in Figure 3-1, the test apparatus allows the temperature and relative humidity (RH) of the challenge gases to be adjusted. To conduct evaluation of a screening technology, a flow of clean air passed through the clean air plenum (Figure 3-1), and an equal flow of air containing a constant concentration of the target CWA passed through one of the other plenums. Each screening technology was connected to the 4-way valve shown in the figure, through which the clean air or CWA challenge gas flowed before being vented into a chemical laboratory hood. For technologies which draw their own sample flow, such as the color indicating tubes, Smiths Detection APD2000, or Proengin AP2C, an appropriate direct connection was made to allow the instrument to sample from the air flow without pressurization by the flow. Color indicating cards were placed within a second enclosure through which the clean air or challenge mixture was directed from the 4-way valve.

Each screening technology was first sampled (or was exposed to) the clean air flow, and any response or indication from the screening technology was noted. After this background measurement, the four-way valve was switched to the challenge plenum to deliver the CWA challenge gas to the subject technology. Switching between the clean air and CWA challenge gas flows was rapid, and the residence time of gas in the test system was short, so that the analysis time determined for each screening technology was not biased by the limitations of the test apparatus. The sequence of exposure to clean air followed by exposure to the CWA challenge gas was carried out three successive times for each screening technology with each CWA. For some of the screening technologies tested, this required using a new color indicating card or tube for each clean air or CWA challenge. For other technologies, a color indicating tube which showed no response on the clean air challenge was used for the subsequent CWA challenge.

Table 3-1 shows the target CWAs used in vapor phase testing, the challenge concentrations used, and the basis for the chosen concentrations. The target concentrations shown for both GB and HD are Acute Exposure Guideline Level (AEGL) values, and specifically AEGL-2 values for a 10-minute exposure.[6] The AEGL-2 value is defined as the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape. AEGL values are established specifically for the protection of personnel, and thus are appropriate target values for AHRF screening. Delivery of the vapor phase CWA challenges was deemed acceptable if the CWA concentration determined by the reference method was within ± 30% of the respective target value shown in Table 3-1.

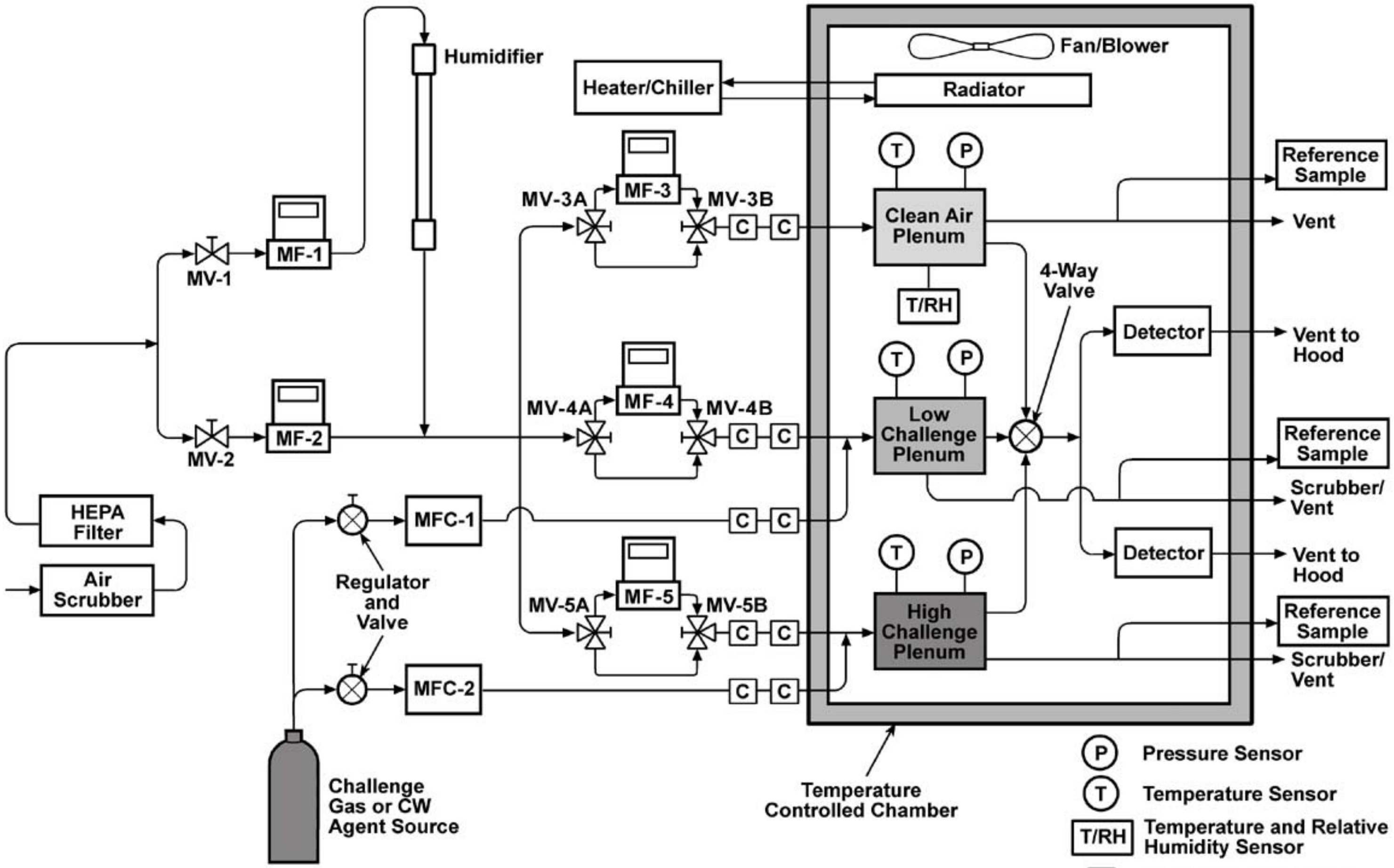

Figure 3-1. Test System Schematic

Table 3-1. Challenge Concentrations for CWA Vapor Testing

CWA	Concentration[a]	Basis for Concentration[b]
Sarin (GB)	0.015 ppm (0.087 mg/m^3)	AEGL-2 value
Sulfur Mustard (HD)	0.09 ppm (0.6 mg/m^3)	AEGL-2 value

a: At normal temperature and pressure, 1 ppm = (MW)(0.0409) milligrams per cubic meter (mg/m^3), where MW is the molecular weight of the compound.
b: AEGL = Acute Exposure Guideline Level.

For each screening technology, the test sequence of three clean air blanks interspersed with three CWA vapor challenges was conducted with one CWA at a time at four different conditions: at a base temperature and RH, at elevated temperature and RH, at low temperature and RH, and at the base temperature and RH with an interferent (a mixture of hydrocarbons characteristic of polluted urban air) added to both the blank and challenge mixtures. However, testing at the base temperature and RH was conducted first, and if a technology failed to respond in all three CWA challenges at that test condition, then no further tests were conducted at the other three test conditions with that CWA. Table 3-2 summarizes the CWA vapor phase test conditions. The interferent was a mixture of about 40 volatile organic compounds, characteristic of gasoline engine emissions in urban air, in a compressed gas standard in nitrogen. This mixture was added to the blank or CWA challenge air flows at a ratio of 1:100 interferent mix to air flow.

Table 3-2. Test Conditions Used in CWA Vapor Testing

Condition	Temperature (°C)	Relative Humidity (%)	Interferent[a]
Base	20	50	None
High T/RH	30	80	None
Low T/RH	10	20	None
Interferent Test	20	50	hydrocarbon mix

a: See text for description.

Reference analysis was used to quantify the CWA concentrations in the clean air and the challenge mixtures, to confirm that the concentrations delivered were within the acceptable tolerance of ±30% from the target value. For both GB and HD, the reference method involved collecting the challenge mixture directly from the test apparatus into gas sample bags. The CWA concentrations were then determined on these samples using a capillary gas chromatograph (GC) with a flame photometric detector (FPD), according to existing HMRC test procedures. Calibration for GB and HD was conducted by diluting stock agent to µg/mL concentrations, and then injecting a 1-µL volume of each standard into the GC-FPD. Concentrations were determined based on a linear regression of peak area with the amount of agent.

3.2.2 Liquid Sample Testing

The testing with CWAs in liquid samples used stock solutions of GB, HD, and VX in isopropyl alcohol (IPA), which were then diluted in IPA or deionized (DI) water to make the challenge samples used in testing the screening technologies. The DI water used was produced by a

Labconco WaterPro PS water purification system in Battelle's laboratory. The dilution with IPA or DI water to make the final challenge solutions was conducted immediately before the start of testing each day, to minimize decomposition of the CWAs in solution. Each of the CWAs was prepared at a single concentration in each of these solvents, and each liquid challenge sample contained a single CWA, i.e., no mixed samples were prepared. Each screening technology was tested with three blank samples of the solvent used to prepare the challenge solutions (i.e., IPA or DI water), and three samples of the corresponding challenge solution containing the CWA. Testing of each screening technology was conducted first with the CWA in the pure solvent. If a technology detected the CWA in at least one of the three challenges in the pure solvent, then the challenge was repeated with diesel fuel added to both the blank and challenge samples as an interferent, at 1% of the total sample volume. Table 3-3 lists the CWAs tested in liquid samples, the concentrations used in the evaluation of liquid screening technologies, and the basis for the concentrations used.

Table 3-3. TIC Concentrations Used in Liquid Testing

CWA	Concentration	Solvent	Basis for Concentration[a]
Sarin (GB)	1 mg/mL	IPA; water	0.5 x RDT&E limit
Sulfur Mustard (HD)	1.5 mg/mL	IPA; water	0.15 x RDT&E limit
VX	0.1 mg/mL	IPA; water	0.1 x RDT&E limit

a: See text for discussion.

Because the purpose of the AHRF screening protocol is to protect analytical personnel from toxic exposures in handling and analyzing samples, the use of CWA challenge concentrations taken from drinking water standards was not appropriate, i.e., it is unrealistic to assume that an analyst would ever ingest a sample provided for analysis. Furthermore, drinking water standards assume the ingestion of several liters of water per day, and lead to allowable concentrations that are too low to be detected by sample screening technologies (e.g., concentrations in the low µg/L, or part per billion (ppb) range for the CWAs). As a result, for this evaluation, the levels set by the U.S. Government for samples in Research, Development, Test, and Evaluation (RDT&E) laboratories were used as a starting point for the CWAs. Allowable RDT&E levels are set specifically to protect laboratory staff from hazards associated with spillage or inadvertent contact with hazardous samples, and thus fit the intent of the AHRF screening protocol. For this test, consistent with the usual practice in Battelle's laboratories, liquid concentrations of the CW agents were kept at a fraction of their respective RDT&E limits.

Most of the liquid sample screening technologies were color indicating papers or cards (M8, M9, or 3-way), and testing of those technologies involved simply applying a drop of the liquid sample to the test paper. The Severn Trent Pesticide Strips and Truetech M272 Water Kit color tickets were tested by wetting the appropriate reagent pad with the liquid sample. The Proengin AP2C was tested with applying a drop of the liquid sample to one of the analyzer's scraper attachments and then heating the scraper while positioned in the inlet of the AP2C analyzer. All liquid sample testing was conducted at room temperature and approximately 50% RH.

Within a few minutes after the challenge samples were prepared by dilution of the IPA stock solutions, samples were collected for reference method analysis by extracting an aliquot of the challenge sample with chloroform. The chloroform extract was then analyzed by the same GC-FPD reference method used for the vapor phase testing. All samples in IPA were stable, and GB and VX were sufficiently stable in water to meet the ±30% requirement in the test/QA plan,[4] but HD was found not to be stable in water samples. The impact of the instability of HD on the water samples test results is discussed in Section 5.1.2.

3.2.3 Surface Sample Testing

The evaluation of screening technologies with surface samples used glass slides as the test surface, and VX as the target CWA. The test samples were prepared by spiking 1 mg (i.e., 1 microliter) of neat VX into a rectangular area of approximately 5 cm^2, marked on the center of a 1 inch x 3 inch glass slide, to produce a surface loading in that 5 cm^2 area of approximately 0.2 mg/cm^2. This loading is such that contact with the test area by unprotected skin would convey one-tenth of the LD_{50} dose of VX by skin absorption for a person of normal size (the LD_{50} dose is that expected to be fatal to half of the exposed population).[4] Test coupons were spiked in the morning of each test day and used immediately after spiking.

Most of the screening technologies tested with surface samples were color indicating papers (M8, M9, or 3-way), and the evaluation was conducted by pressing the paper onto the test sample and inspecting the paper for a color change. The Agentase CAD Kit color indicating pen was tested by preparing the pen according to the manufacturer’s instructions, and then swabbing the center of the test coupon with the porous pen tip and inspecting the tip for a color change. The Proengin AP2C was tested by scraping the center of a test coupon with one of the AP2C scraper attachments, and then heating the scraper while positioned in the inlet of the AP2C analyzer.

Tests were conducted with each technology using three blank glass coupons, and three glass coupons spiked with VX, at room temperature and approximately 50% RH. For those technologies that correctly indicated the presence of VX in at least one of these three tests, interference challenges were then conducted by spiking approximately 1 mg of diesel fuel per coupon onto both blank and VX-spiked coupons. Furthermore, for those same technologies, the blank and spiked coupon tests (without interferent) were repeated at the same Low and High temperature and RH conditions used for the CWA vapor testing (Table 3-2).

3.3 Data Recording

Because of the qualitative nature of most of the technologies being tested, the test observations were recorded manually by the testing personnel on hard copy data sheets prepared for this purposes. Upon completion of testing, the data sheets were reviewed and signed by a Battelle staff member not conducting the testing but familiar with the test procedures. The data were then entered from the hard copy data sheets into an Access® electronic database, which was used for data analysis relative to the performance parameters being tested.

4.0 Quality Assurance/Quality Control

Quality assurance/quality control (QA/QC) procedures were performed in accordance with the QMP for the TTEP program[5] and the test/QA plan for this verification test.[4] QA/QC procedures and results are described below for the vapor- and liquid-phase TIC testing. Three deviations from the test/QA plan[4] occurred in this testing:

- In a few tests with GB vapor at room temperature, the RH exceeded the target upper limit of 55%. Those tests were not repeated, as the conditions were not severely different from the target conditions, but care was taken to maintain target RH in all other tests.

- In testing with VX in water, reference analyses were not conducted for VX. Reference analyses for GB were used as a surrogate for VX analysis, for the reasons described in Section 4.2.

- In testing the Proengin AP2C or screening VX on test coupons at high T/RH conditions, the three challenge coupons were analyzed first, and then the three blank coupons, rather than the two types being interspersed. This error is noted in Section 5.1.3.

None of these deviations had a significant effect on the results of this test. These deviations were documented on appropriate forms which are retained by the Battelle Quality Manager.

4.1 Blank Samples

As described in Section 3, challenges with CWA samples were interspersed with corresponding blank challenges. In vapor testing, blank samples consisted of clean air at the same temperature and RH as that used to dilute the CWAs. In liquid sample testing, blanks consisted of the same high purity IPA and water used as solvents for the challenge samples. Surface blanks consisted of clean glass coupons unspiked with VX. None of the blank samples produced any indication of CWA contamination when analyzed with the applicable reference methods.

As described in Section 5.2.1, a few false positive responses were observed from the screening technologies. However, those do not appear to be related to the cleanliness of the blank samples. The most notable and false positive responses occurred with blank IPA samples, and appear to be the result of incompatibility of the screening technologies with that solvent.

4.2 Reference Analyses

Reference analyses were made of the CWA challenge concentrations delivered during testing, to confirm that those concentrations were within ±30% of the target concentrations shown in Section 3. In general, testing was not conducted unless the CWA challenge concentrations were within that allowable range; HD in aqueous samples was one exception that is described below.

In vapor phase CWA testing, for both GB and HD, the reference method involved collecting the challenge mixture directly from the test apparatus into gas sample bags. The CWA concentration was then determined using a capillary GC-FPD, according to existing HMRC test procedures. Calibration for GB and HD was conducted by diluting stock agent to µg/mL concentrations, and then injecting a 1-µL volume of each standard into the GC-FPD. Concentrations were determined based on a linear regression of peak area with the amount of agent.

In liquid sample testing, the same GC-FPD analysis method was used as the reference method. Within minutes after the liquid challenge samples were prepared in IPA or water by dilution of the IPA stock solutions, aliquots of the challenge samples were extracted with chloroform. Testing with the challenge samples then began, while in parallel the chloroform extracts were analyzed for GB or HD, as appropriate, by the GC-FPD reference method. Specific analysis for VX proved difficult and too time-consuming for effective use in guiding the testing. Instead, the reference results for the simultaneously prepared GB samples were used as a surrogate to indicate the stability of VX in the samples. The slower hydrolysis rate of VX in water relative to that of GB (i.e., about 1% per hour, as opposed to about 3% per hour for GB) makes this an appropriate approach.[7] These reference analyses showed that all challenge samples prepared in IPA were stable. In addition GB (and by inference VX) challenge samples prepared in water met the ±30% requirement in the test/QA plan.[4] However, HD was found not to be stable in water samples. Loss of as much as 90% of the HD was seen in the water samples, between the time of preparation and the time of analysis of the chloroform extract shortly thereafter. This finding was not entirely unexpected, given the known rapid hydrolysis rate of HD (about 5% per minute).[7] The impact of the instability of HD on the water sample test results is discussed in Section 5.1.2.

Because of the difficulty with VX analysis noted above in discussion of the liquid samples, it was concluded that the extraction and analysis steps necessary to determine the amount of VX on the surface test coupons would have greater uncertainty than the volumetric application of the neat agent to the coupon by micro pipette. That is, the application of VX to the surface was judged sufficiently reliable that confirmation of the VX dose by reference analysis was not needed.

The decision not to conduct specific analysis for VX in liquid and surface testing was formally documented as a deviation from the procedures stated in the test/QA plan,[4] and was filed with the Battelle QA Manager.

4.3 Audits

Two types of audits were performed during the CWA testing: a technical systems audit (TSA) of the vapor phase test procedures, and a data quality audit of the recorded test data from the vapor, liquid, and surface testing. Audit procedures and results are described below.

4.3.1 Technical Systems Audit

A Battelle Quality Management representative conducted a TSA of the CWA vapor testing procedures at the HMRC on February 20, 2007. The purpose of that TSA was to ensure that the test was being conducted in accordance with the test/QA plan[4] and the TTEP QMP.[5] In the TSA, the test procedures were compared to those specified in the test/QA plan,[4] and data acquisition and handling procedures, as well as the reference standards and methods, were reviewed. Observations and findings from the TSA were documented and submitted to the Battelle Task Order Leader for response. The only finding of this TSA was that the calibrations of certain flow meters used in diluting the vapor phase CWAs were out of date. The flow measurements made with these flow meters are not a critical part of the CWA delivery (i.e., challenge vapor concentrations are set based on the reference method analyses, not on flow readings), so substitution of appropriately calibrated flowmeters and labeling of selected flow meters as non-critical was an acceptable response to address this QA issue. Records from the TSA are permanently stored with the Battelle Quality Manager.

4.3.2 Data Quality Audit

At least 10% of the data acquired during each of the CWA vapor, liquid, and surface testing were audited. Battelle's Quality Manager traced the data from the initial handwritten data record through to final reporting, to ensure the integrity of the reported results. All summaries and calculations performed on the data undergoing the audit were checked.

4.4 Data Review

Records generated in this test received a one-over-one review before these records were used to calculate, evaluate, or report verification results. Data were reviewed by a Battelle technical staff member involved in the verification test. The person performing the review added his/her initials and the date of the review to a hard copy of the record being reviewed.

5.0 Test Results

The primary results of this evaluation of potential AHRF sample screening technologies consist of the observed responses to the CWA challenges, which establish the accuracy of each technology for sample screening. Those responses were also reviewed to determine false positive and negative rates for each technology, and to establish the repeatability of responses for those few technologies tested that provide more than a qualitative (yes/no) response. Analysis time and operational factors were also evaluated based on operator observations and test records.

5.1 Accuracy

The test results for each technology were compiled into databases that list the technology name, the target CWA and its test concentration, reference method results confirming the delivered CWA concentration, the test conditions (e.g., T, RH, presence/absence of interferent), and the technology's response to the triplicate blank and challenge runs. The database of vapor phase CWA results is included in this report as Appendix A, the database of liquid sample CWA results as Appendix B, and the database of surface sample results as Appendix C. To make these test results immediately understandable, a condensed version of each database has been prepared, in which color coding of the test results is used to provide a visual indication of screening technology performance. In this format, a technology which provides a positive response to all three challenges in a single test condition with a CWA is indicated with the color green; positive responses in only one or two of the three challenges are shown by the color yellow, and the absence of a positive response in all three challenges is shown by the color red. This condensed summary of screening technology performance is shown in Table 5-1 for those technologies tested with vapor phase CWAs, in Table 5-2 for those technologies tested with CWAs in liquid samples, and in Table 5-3 for those technologies tested with VX on surfaces.

5.1.1 Vapor Samples

Table 5-1 shows that of the 10 technologies tested with GB vapor, five showed correct positive responses at the base test condition. Those five technologies were subsequently subjected to testing with the hydrocarbon interferent, and at Low and High temperature and RH conditions. It is noteworthy that for some of these five technologies, accurate detection of GB vapor at the challenge concentration of 0.015 ppm (0.087 mg/m^3) would not necessarily have been predicted based on the vendors' stated detection limits. For example, the Draeger Civil Defense Kit had a stated detection limit for GB of 0.025 ppm, but responded clearly and consistently to the GB challenges in this evaluation. With this detection capability these technologies offer greater protection in sample screening for GB than would be suggested by their stated detection limits.

Table 5-1 also shows that all five of the screening technologies that correctly detected GB vapor at the base condition also did so with the hydrocarbon interferent present, and at the Low and High temperature/RH conditions. Thus, these five technologies all exhibited accuracy of 100% for GB vapor detection. However, a few unusual observations were noted with these

Table 5-1. Summary Results of CWA Vapor Testing

Technology	CWA	Test Condition[a, b]			
		Base	Base + Int.	Low	High
Anachemia C2					
Color Ticket	GB			c	
Color Tubes	HD			d	d
Anachemia CM256A1					
Multifunction Card	GB				
	HD				
Draeger Civil Defense Kit	GB		e		
	HD				
MSA Single CWA Kit	GB		f		
	HD				
Nextteq Civil Defense Kit					
Color Tubes	GB				
	HD				
Proengin AP2C	GB				
	HD				
RAE MultiRAE Plus	GB				
	HD				
S. S. HazMat Smart Strip	GB				
Smiths Detection APD2000	GB				
	HD		g		h
Truetch M18A3 Ticket	GB				

a: Base = room T and 50% RH; Base + Int. = room T, 50% RH, and gas exhaust hydrocarbon mixture at 1% of total flow; Low = 10°C and 20 %RH; High = 30°C and 80 %RH.

b: Green = proper response in all 3 challenges; Yellow = proper response in 1 or 2 of the 3 challenges; Red = no responses in the 3 challenges. Absence of color indicates test not conducted.

c: A faint yellowish color (indicative of neither a positive nor negative response) observed in indicator area in 2 of 3 blank challenges.

d: Faint positive responses observed, but all blank and challenge runs produced the same color response.

e: Strong positive (red) responses were observed with the GB challenge, and a weak(light pink) response was seen with the blank (i.e., interferent only) challenges.

f: Strong positive (yellow) responses were observed with the GB challenge, and a weak (faint yellowish) response was seen with the blank (i.e., interferent only) challenges.

g: Only one positive response was observed, and that occurred while sampling the blank (clean air).

h: All responses were correct, however the unit was observed to switch into its AutoCal mode without any input from the test operators.

Table 5-2. Summary Results of CWA Liquid Testing

Technology	CWA	Solvent and Composition[a,b]			
		IPA		Water	
		Base	Base+Int	Base	Base+Int
Anachemia					
C2 3-way paper	GB				
	VX				
	HD				
CM256A1 3-way paper	GB				
	VX				
	HD				
Nextteq Civil Defense Kit					
M8 paper	GB				
	VX				d
	HD			d	
M9 paper	GB	c			
	VX	c			
	HD	c			
3-way paper	GB				
	VX				
	HD				
Proengin AP2C	GB	d			
	VX	d			
	HD	d		d	
Safety Solutions					
HazMat Smart Strip	GB				
	VX				
HazMat Smart M8	GB				
	VX				
	HD				
Severn Trent Eclox Strip	GB	c			
	VX	c			
Truetech					
M272 Wtr Kit color ticket	GB	c			
	VX	c			
M18A3 M8 paper	GB				
	VX				
	HD				

a: IPA = isopropyl alcohol; Base = challenge sample with CWA concentration shown in Table 3-3, and Base+Int = same challenge sample with diesel fuel added at 1% by volume as interferent.
b: Green = proper response in all three challenges; Yellow = proper response in 1 or 2 of the 3 challenges; Red = no response or incorrect response in all 3 challenges. Absence of color means test not conducted.
c: Technology also gave positive responses to the blank solvent.
d: See section 5.1.2 for a detailed explanation of performance under this condition.

Table 5-3. Summary Results of CWA Surface Testing[a]

Technology	Test Condition[b, c]			
	Base	Base + Int.	Low	High
Agentase CAD Kit				
Anachemia C2				
3-way paper		d		
Anachemia CM256A1				
3-way paper		d		
Nextteq Civil Defense Kit				
M8 paper		d		
M9 paper				
3-way paper		d		
Proengin AP2C				e
Safety Solutions				
HazMat Smart M8		d		
Truetch M18A3				
M8 paper		d		

a: All surface testing done with VX as the target CWA.

b: Base = room T and 50% RH; Base + Int. = room T, 50% RH, diesel fuel as interferent; Low = 10°C and 20 %RH; High = 30°C and 80 %RH.

c: Green = proper response in all three challenges; Yellow = proper response in 1 or 2 of the 3 challenges; Red = no responses in the 3 challenges. Absence of color indicates test not conducted.

d: These papers showed a pink color when challenged with blank test coupons spiked with only diesel fuel; this was clearly different from the dark green color shown when VX was also present.

e: See section 5.1.3 for a detailed explanation concerning performance under this condition.

technologies in the GB vapor testing. The Anachemia C2 color ticket showed a faint yellow color in its indicator area in two of the three blank (i.e., clean air) challenges at the Low temperature/RH condition. These are neither positive nor negative indications with this technology. Also, the Draeger Civil Defense Kit showed a faint pink color, and the MSA Single CWA Sampler Kit a faint yellowish color, suggesting a weak positive response with the blank samples during interferent testing at the base temperature/RH conditions. Those blank sample results are considered false positive responses.

Table 5-1 also shows that of the eight technologies tested with HD vapor, four showed correct positive responses at the base test conditions. Those four technologies were subsequently subjected to testing with the hydrocarbon interferent, and at Low and High temperature and RH conditions. Notably, for each of these four technologies the HD vapor challenge concentration of 0.09 ppm (0.6 mg/m^3) was lower than the technology's stated detection limit for HD. These technologies thus offer greater protection in sample screening for HD vapor than would be suggested by their stated detection limits.

Unlike the situation with GB, the screening technologies that successfully detected HD vapor at the base condition did not necessarily do so at all other test conditions. The Draeger Civil Defense Kit and Nextteq Civil Defense Kit both gave correct positive responses at all four test conditions in Table 5-1, and thus achieved 100% accuracy for HD detection. However, the Anachemia C2 color tubes showed no response to HD vapor challenges with the interferent mixture present, and showed no difference between blank and HD challenge sample responses at both the Low and High temperature/RH conditions. The result is 25% accuracy of HD detection for that technology. The Smiths Detection APD2000 gave correct positive responses at the base test condition and at both Low and High temperature/RH conditions, but gave no response to the HD challenges when the hydrocarbon interferent mixture was also present. At that condition, the only positive response occurred while sampling the clean air blank; that response is a false positive. An accuracy of 75% in HD detection results for the Smiths Detection APD2000.

An unusual observation was also made in HD vapor testing with the Smiths Detection APD2000 at the High temperature/RH condition. The test operators observed that the APD2000 switched into its AutoCal mode multiple times during normal operation at that condition, without intervention by the operators. In each case the operators switched the APD2000 back into routine monitoring mode and continued the test. It should be noted that proper operation of the APD2000 was always checked before testing with the simulant source supplied with the unit, and this check was sometimes repeated during testing. All such checks confirmed proper operation of the APD2000.

5.1.2 Liquid Samples

Table 5-2 summarizes the screening results with liquid samples, showing for each technology the CWAs used in testing and the results with both IPA and water samples, both without and with diesel fuel added as an interferent. Table 5-2 shows that few successful screening results were obtained with the liquid samples. Testing with the challenge solutions in IPA was especially problematic, as the great majority of the screening technologies produced no positive responses with the IPA samples. Furthermore, as the footnotes to Table 5-2 indicate, the three technologies which did give a positive response to the IPA challenge solutions also responded positively to the blank IPA solvent. As a result, no interferent tests were run with any of the technologies with IPA samples. The most extreme response to the IPA samples was exhibited by the Proengin AP2C, which displayed the highest response level of every alarm when challenged with blank IPA solvent (i.e., simultaneous five-bar indications of HD/HL, HN/AC, G/V, and L/SA, as well as the hydrocarbon indication CH). Because of this extreme response, no testing was done of the AP2C with IPA solutions other than the blank solvent.

One explanation for the lack of successful screening results with the IPA samples may be that the technologies are not designed for application to non-aqueous solvents. This is certainly plausible for the M8 and 3-way color indicating papers tested. However, the water sample results in Table 5-2 indicate that the simple inability to detect the CWAs at the target screening levels may also be a key factor. With the water samples, positive indications of the CWAs were found with only four technologies. The Severn Trent Eclox Pesticide Strip and Truetech M272 Water Kit color ticket both responded correctly to the GB and VX challenge samples in water, and gave no response to blank water samples. They also gave correct responses when diesel fuel was present in the blank and challenge samples. Accuracy thus was 100% for those two technologies in detecting GB and VX in water. The Proengin AP2C responded correctly to GB in all challenges both with and without the diesel fuel interferent, resulting in accuracy of 100% for GB, but gave no response to VX. With HD samples, the Proengin AP2C gave correct but very brief (approximately one second duration) indications of HD/HL in two of the three challenges, but gave strong indications of HD/HL with all three challenges when the diesel fuel interferent was also present. Overall accuracy for HD thus was 83% (5 out of 6 challenges). The Nextteq Civil Defense Kit M8 paper did not respond to GB in the water samples, but with all three VX samples showed a light yellow color, which is a positive response for GB rather than for VX. Those responses were recorded as correct because they are indicative of a nerve agent and provide a protective response for laboratory personnel. When diesel fuel was also present in the water sample with VX, the Nextteq M8 paper showed the light yellow positive response in only two of the three challenges. Overall accuracy for the Nextteq M8 paper for VX thus was 83%. With HD in water, the Nextteq M8 paper gave positive responses in two out of three challenges, but gave no positive responses when diesel fuel was also present, resulting in 33% accuracy (2 of 6 challenges). Very little information was available on the expected detection limits of these technologies for CWAs in water, so it is not possible to compare expected and observed performance for these technologies.

It should be noted that the stability of HD in the water samples may affect the test results shown in Table 5-2. All three CWAs are stable in the IPA samples, but in water the hydrolysis of the CWAs can be significant. For GB and VX, published hydrolysis rates are about 3% per hour and 1% per hour, respectively.[7] Based on the time required to prepare, analyze, and use the challenge samples of these CWAs in water, relatively little loss of these CWAs would be expected during testing, and indeed the reference analyses confirm that expectation. However, for HD the hydrolysis rate is about 5% per minute,[7] and considerable decomposition of HD in water solution would be expected during testing. In fact that was observed, as up to 90% loss of HD from the water challenge solutions was seen by reference analyses, despite efforts to use the challenge samples soon after they were prepared. Consequently, the results for HD screening may underestimate the ability of the tested technologies to detect HD in water samples. However, it should be noted that the rapid decomposition of HD in water will happen with real samples, and will minimize the likelihood that water samples containing HD will actually enter the AHRF. The decomposition products of HD are thiodiglycol and 1,4-thioxane in a roughly 4:1 ratio.[7] Both compounds are much less toxic than HD itself.

A final comment on the liquid sample testing is that the Proengin AP2C scraper attachments were difficult to wet with the water samples, i.e., water tends to run off the surface of the scraper. According to the records of the testing personnel, this was less of a problem with the challenge samples containing CWAs than with blank water samples.

5.1.3 Surface Samples

Table 5-3 shows that all nine of the screening technologies tested with surface samples were successful in detecting VX on the surface coupons, whether at the base condition, with diesel fuel present as an interferent, or at Low or High temperature and RH. Thus all nine screening technologies tested in this manner were 100% accurate in detecting VX on the coupon surfaces under these test conditions.

As indicated in the footnote to Table 5-3, all of the M8 and 3-way papers also showed a pink color after contact with the coupons spiked with only diesel fuel. This color change does not resemble the color changes that indicate the presence of VX. As a result, these responses are not considered false positives, but are noted for the information of potential users of these papers.

The only other unusual response noted with the surface samples occurred with the Proengin AP2C at the High temperature and RH condition (Table 5-3). At that test condition, the three challenge coupons (spiked with VX) were screened before the three blank coupons were screened. The Proengin AP2C responses to the VX challenge coupons were markedly more intense than the corresponding challenge responses at other test conditions, and the response was very slow to clear after the challenge was completed. In fact, even several minutes after screening a challenge coupon, the Proengin AP2C still showed a one-bar G/V response that did not completely clear. Screening of the next challenge coupon at the High temperature and RH condition then produced the strong G/V response, which again only slowly decreased after the challenge. When the three blank coupons were subsequently screened, the first produced a three-bar response indicating HD/HL, the second produced a brief one-bar response indicating G/V, and the third produced a brief hydrocarbon (CH) indication. The first two of these blank coupon responses are considered false positives. However, these observations are more suggestive of a memory effect with the Proengin AP2C in screening VX at the High temperature and RH condition, which caused slow recovery of readings after a challenge, and contributed to the false positive responses on the first two blanks. It is unknown why this behavior was observed at the High temperature and RH condition, and not at the base or Low temperature and RH conditions.

5.2 False Positive/False Negatives

5.2.1 False Positives

Testing for false positive responses was done through challenges with a completely blank sample (i.e., clean air in the vapor testing, pure solvents in the liquid testing, and a clean coupon in the surface testing), and through challenges with interferent in the absence of a target CWA (i.e., the hydrocarbon mixture in air in the vapor testing, and the diesel fuel in liquid and surface testing). In the GB vapor testing, three weak false positive responses were seen with the Draeger Civil Defense Kit, and with the MSA Single CWA Sampler Kit, with clean air plus the added hydrocarbon mixture (Table 5-1). In the HD vapor testing, the Smiths Detection APD2000 gave a false positive response to one of the three blank challenges with the hydrocarbon interferent mixture.

In liquid sample testing false positives were observed only with the IPA solvent blanks, as discussed in Section 5.1.2, likely due to incompatibility of the screening technologies with that solvent. The Proengin AP2C in particular responded positively with every possible alarm when tested with blank IPA samples. No false positives occurred with any water samples.

In the surface sample testing the only two false positive readings were with the AP2C at the High temperature and RH condition, as discussed in Section 5.1.3. Those appeared to be the result of slow clearance of the AP2C readings after challenge runs at those conditions.

5.2.2 False Negatives

False negatives are shown by the red or yellow cells in Tables 5-1 and 5-2, which indicate the absence of a response in all three CWA challenges, or in one or two challenges, respectively. For clarity, Table 5-4 draws information from Tables 5-1 and 5-2 (excluding the results with IPA solutions) to list the false negative responses observed in the vapor and liquid CWA testing. No false negatives occurred in the surface testing (Table 5-3).

In the vapor testing, most of the false negatives were due to the inability of the technology to detect the CWA at the vapor challenge concentration under the base test conditions. The only exceptions were that the Anachemia C2 color tubes were ineffective at detecting HD at any condition except the base condition, and the Smiths Detection APD2000 did not detect HD when the hydrocarbon interferent mixture was also present.

Similarly in the liquid testing, almost all false negatives occurred due to the complete inability of the technologies to detect the CWAs in the base test condition, i.e., in otherwise clean water at the challenge concentrations. Also, the Nextteq M8 paper showed an effect of the diesel fuel interferent, in the form of one false negative for VX with that interferent present (as opposed to no false negatives without the interferent), and three false negatives for HD with that interferent present (as opposed to one without the interferent). The Proengin AP2C also showed one false negative response for HD at the base test condition.

False negative responses are of great concern in the AHRF sample screening process, so an assessment was made of how the expected detection capabilities of the screening technologies compare to the actual detection behavior summarized in Table 5-4. This assessment could only be done for vapor phase CWA detection, as summarized in Table 5-1, because very little information was available from the technology vendors on the likely detection limits of their technologies for CWAs in the liquid phase. Even for vapor phase CWA detection, stated detection limits were not available from the vendors for all the technologies tested. Regarding the detection of GB vapors, the Anachemia CM256A1 multifunction card, the Nextteq Civil Defense Kit color tubes, and the Smiths Detection APD2000 all failed to detect that CWA even though the target challenge concentration was equal to or greater than the stated detection limit for the technology. The RAE MultiRAE Plus did not detect GB, as expected based on its stated detection limit, and the GB detection limit of the Safety Solutions HazMat Smart Strip was unknown. Regarding HD vapor detection, the Proengin AP2C was the only technology among those that failed to detect HD that had a stated detection limit lower than the challenge concentration.

Table 5-4. Summary of False Negative Responses

Technology	CWA	Number of False Negatives	Condition
Vapor[a]			
Anachemia			
C2 Color tubes	HD	3 each	Base + Int., Low, High
CM256A1 Multf'n Card	GB, HD	3 each	Base
MSA Single CWA Kit	HD	3	Base
Nextteq Civil Defense Kit	GB	3	Base
Proengin AP2C	HD	3	Base
RAE MultiRAE Plus	GB, HD	3 each	Base
S.S. HazMat Smart Strip	GB	3	Base
Smiths Detection APD2000	GB	3	Base
	HD	3	Base + Int.
Liquid[b]			
Anachemia			
C2 3-way paper	GB, VX, HD	3 each	Base
CM256A1 3-way paper	GB, VX, HD	3 each	Base
Nextteq			
M8 paper	GB	3	Base
	VX	1	Base +Int
	HD	1 (3)	Base (Base +Int)
M9 paper	GB, VX, HD	3 each	Base
3-way paper	GB, VX, HD	3 each	Base
Proengin			
AP2C	VX	3	Base
	HD	1	Base
Safety Solutions			
HazMat Smart Strip	GB, VX, HD	3 each	Base
HazMat Smart M8	GB, VX, HD	3 each	Base
Truetech			
M18A3 M8 paper	GB, VX, HD	3 each	Base

a: See Table 5-1.
b: See Table 5-2. False negative responses with IPA solvent in liquid sample testing are not listed; that solvent not compatible with many screening technologies.

5.3 Analysis Time

The time required to screen a sample with each of the screening technologies was determined by the effort required for sample collection (e.g., drawing of air sample with a hand pump) or manipulation (e.g., mixing of reagents, breaking of tubes), as well as by the inherent response time of the detection principle of each technology. Table 5-5 summarizes the analysis time observations for each technology, listing the type of samples (vapor, liquid, or surface), the approximate typical analysis time characteristic of each technology, and comments on the analysis time. Table 5-5 includes only those technologies which actually gave a response to at least one CWA at the base test condition for one or more sample types, i.e., a technology which did not respond does not have a measurable response time. It should be noted that these results apply to the target CWA concentrations used in this test. The presence of higher concentrations may produce more rapid responses with some technologies.

Table 5-5 shows that many of the screening technologies responded to the challenge samples within seconds. Among the longest analysis times (up to approximately three minutes) were those for the Anachemia, Severn Trent, and Truetech color tickets, which require substantial reaction time. The Anachemia, MSA, and Nextteq color indicating tubes also had analysis times of a few minutes, due to the time to draw the air sample through the tube. It should be noted that for the Proengin AP2C, the analysis times shown for liquid and surface samples are determined from when the scraper attachment is inserted into the AP2C inlet and heated to drive any CWA into the AP2C. The process of then disposing of the used scraper tip, attaching a new scraper tip, and contacting the next liquid or surface sample will require additional time (perhaps 15 to 30 seconds per sample in routine operation).

5.4 Repeatability

None of the screening technologies tested for detection of CWAs provided a quantitative indication of CWA concentration. As a result, no such readings exist from the CWA testing with which to evaluate repeatability. (Repeatability of quantitative readings was evaluated for a few technologies in the corresponding TIC screening report.[3])

5.5 Operational Factors

Operational factors were assessed based on the observations of the test operators, and are summarized in Table 5-6, which for each CWA technology describes the general ease of use, any problems noted in using the technology, and the physical effort required for use. The latter issue was included because a few of the vapor sampling technologies rely on drawing sample air through a colorimetric tube using a hand pump, and such effort can become tedious if performed repetitively. Note that in Table 5-6 the several types of very similar test papers (M8, M9, and 3-way) from different vendors (Anachemia, Nextteq, Safety Solutions, and Truetech) are grouped together for discussion of operational factors.

Table 5-5. Summary of Sample Analysis Times[a]

Technology	Sample Type	Analysis Time[b]	Comments
Agentase CAD Kit	Surface	Sec	Color change within 1 second at room conditions, up to 26 seconds at Low T/RH or with diesel fuel present
Anachemia C2			
Color Ticket	Vapor	Min	Response within 2 minutes, due to reaction time needed for color change
Color Tubes	Vapor	Min	A few minutes needed for 40 pump strokes
3-way Paper	Surface	Sec	Color change within 5 seconds
Anachemia CM256A1			
3-way Paper	Surface	Sec	Color change within 5 seconds
Draeger Civil Defense Kit	Vapor	Sec	Initial response within a few pump strokes; a few minutes required for requisite 50 pump strokes
MSA Single CWA Kit	Vapor	Min	2 minutes (10 pump strokes) needed
Nextteq Civil Defense Kit			
M8 Paper	Liquid/Surface	Sec	Color change within about 10 seconds with liquid and surface samples.
M9 Paper	Surface	Sec	Color change within 25 seconds
3-way Paper	Surface	Sec	Color change within 5 seconds
Color Tubes	Vapor	Min	Sample drawn for 3.5 minutes
Proengin AP2C	Vapor	Sec	Response within 10 seconds
	Liquid/Surface	Sec	Water responses within 10 seconds; surface responses within 25 seconds.
Safety Solutions			
HazMat Smart M8	Surface	Sec	Color change typically within 5 seconds
Severn Trent Eclox Strip	Liquid	Min	Response within 3 minutes, due to reaction time needed for color change.
Smiths Detection APD2000	Vapor	Sec	Most responses within 30 seconds
Truetech			
M18A3 Color Ticket	Vapor	Min	Response within 3 minutes, due to reaction time needed for color change
M18A3 M8 Paper	Surface	Sec	Color change within 10 seconds
M272 Color Ticket	Liquid	Min	Response within 3 minutes, due to reaction time needed for color change

a: Only technologies that detected at least one CWA in at least one sample matrix are listed here.
b: Indication of whether typical time to respond is in minutes (Min) or seconds (Sec).

Table 5-6. Summary of Observations on Operational Factors of the Technologies

Technology	General Ease of Use	Problems with Use	Physical Effort Needed
Agentase CAD Kit	Simple procedure of bending pen to break internal reagent capsule and wiping surface with pen tip	No problems.	Minimal
Anachemia C2 Color Tubes	Relatively complex procedure (with some analytes) of breaking tube, inserting into pump, drawing sample through, then adding reagent to tube	Sample tube packets say not to use after September 10 with no specific year indicated - distributor says 2010; pump difficult to use, and could not tell if working properly	Arm/hand strength needed for pump
Anachemia C2 Color Ticket	Simple procedure of wetting reagent pad, exposing to air, and pressing second pad onto the first to produce color change	No problems.	Minimal
Anachemia CM256A1 Multifunction Card	Moderately simple procedure of breaking ampoules on a card to wet/activate test patches and exposing patches to sample; easily distinguishable color changes	Breakage of two green ampoules at one time causes rapid exothermic reaction - creates fumes and sprays green liquid	Minimal
Color Indicating Papers (M8, M9, 3-way)	Very simple to use, require only contacting paper with sample or surface to be tested and observing color change; multiple types and vendors	No problems	Minimal. Papers can be cut into smaller pieces for use to extend supply
Draeger Civil Defense Kit	Simple procedure of breaking tubes, inserting into manifold, and drawing sample through tubes; easily distinguishable color changes; five compounds can be tested for at one time	Prolonged use can cause fatigue to hands; Draeger sells five-tube sets to be used with kit which are approximately five times more expensive on a per-tube basis compared to single tubes purchased separately	Hand strength needed for pump operation
MSA Single CWA Kit	Simple procedure of breaking tube and inserting into pump	Prolonged use can cause hand fatigue; squeeze counter on pump broke after a couple uses	Hand strength needed for pump operation
Nextteq Civil Defense Kit Color Tubes	Simple procedure of breaking tubes, inserting into manifold, and drawing sample through tubes; five compounds can be tested for at one time	Impregnating adsorbent layer by breaking liquid ampoules sometimes difficult; electric pump flow was easily disrupted causing pump to stop	Minimal effort with electric pump; manual pump also available
Proengin AP2C	Direct air sampling instrument; simple procedure of starting device and observing readings (for vapors), or taking sample with scraper tip, heating scraper tip inline with device and observing readings (for liquids and surface samples)	No problems; low-pressure hydrogen supplies will need replacement periodically in regular use (12-hour supply life easily maximized by turning instrument on and off)	Minimal
RAE MultiRAE Plus	Direct air sampling instrument; simple procedure of starting device and waiting for electronic reading	PID sensor did not respond to CWAs	Minimal
Safety Solutions HazMat Smart Strip	Peel off protective cover for immediate use	Instructions say mainly used for aerosols making reliability of vapor and liquid tests uncertain; no response to vapor or liquid samples	Minimal

Table 5-6. (Continued)

Technology	General Ease of Use	Problems with Use	Physical Effort Needed
Severn Trent Eclox Pesticide Strip	Simple procedure of wetting pad with sample, and pressing together with a second reagent pad	No problems.	Minimal
Smiths Detection APD2000	Direct air sampling instrument; simple procedure of starting instrument and observing readings	No problems. Chemical surrogate vapor source provided with instrument provides rapid indication of proper operation. APD2000 contains a small radioactive source.	Minimal
Truetech M18A3 Color Ticket	Simple procedure of wetting reagent pad, exposing to air, and pressing second pad onto the first to produce color change	No problems.	Minimal
Truetech M272 Water Kit Color Ticket	Simple procedure of wetting pad with sample, and pressing together with a second reagent pad	No problems.	Minimal

Table 5-6 shows that most of the CWA screening technologies were simple and reliable to use. The most common operational difficulty noted was the operator fatigue that occurred with repeated use of hand pumps to draw air through the color indicating tubes. Substitution of an electric pump or other automated sampling system would be a potential remedy if such technologies were used repeatedly in the AHRF. Test operators reported that the direct air sampling instruments (Proengin AP2C, RAE MultiRAE Plus, and Smiths Detection APD2000) were all simple to use and understand, and operated reliably (though with different levels of success in CWA detection) in this evaluation. The Smiths Detection APD2000 was the one detector tested that incorporates a small radioactive source. Proper disposal of this source will be required should the instrument need to be discarded. The Proengin AP2C uses an internal low-pressure hydrogen supply, which will require occasional replacement. The useful life of the hydrogen supply can be extended by turning the FSP off between measurements, and the operators reported no adverse behavior when the AP2C was operated in this way during the evaluation.

5.6 Screening Technology Costs

In choosing technologies for screening large numbers of samples in an AHRF, both the initial cost of a CWA screening technology and the cost per sample of the technology in extended use are important. Table 5-7 summarizes the cost information for each technology tested, showing the identity of each technology, the purchase price of the technology as tested, and the per-sample cost of consumable items.

Table 5-7 shows that the purchase costs of most of the screening technologies are approximately $3,000 or less, with the Smiths Detection APD2000 and Proengin AP2C the exceptions at approximately $10,000 and $16,000, respectively. (As noted in the table, the Proengin AP2C purchase price was a discount from the vendor because of the nature of this program; the normal purchase price is likely to be approximately 30% higher.) However, comparison of the purchase

Table 5-7. Cost Information on CWA Screening Technologies

Vendor	Technology	Technology Cost	Consumable Items	Cost per Sample[a]
Agentase	CAD Kit	$286	Color indicating pens (pack of 5)	$47
Anachemia	C2	$684	Color tubes (pack of 5)	$7
			3-way paper (booklet)	<$0.50
			Color ticket	$9
	CM256A1	$189	Multifunction card	$17
			3-way paper (booklet)	<$0.50
Draeger	Civil Defense Kit	$3,114	Tubes (boxes of 10)	GB: $11 HD: $9
MSA	Single CWA Sampler Kit	$1,295	Tubes (boxes of 10)	GB: $8 HD: $8
Nextteq	Civil Defense Kit	$1,875	Tubes (boxes of 10)	GB: $5 HD: $5
			M8 paper (booklet)	<$0.50
			M9 paper (roll)	<$0.50
			3-way paper (booklet)	<$0.50
Proengin	AP2C	$15,708 (discount for testing)	Hydrogen supplies; batteries. Scraper tips for liquid sampling (packs of 10).	<$3[b] plus $4 (for liquid or surface sampling)
RAE Systems	MultiRAE Plus	$3,290	Batteries	<< $1
Safety Solutions	HazMat Smart Strip	$20	Card	$20
	HazMat Smart M8	$6	Card	$6
Severn Trent	Eclox Pesticide Strip	$510	Color tickets (pack of 25)	$20
Smiths Detection	APD2000	$9,620	Batteries	<<$1
Truetech	M272 Water Kit	$386	Color tickets (purchased as part of kit)	~$4[c]
	M18A3	$1,189	Color tickets (purchased as part of kit)	~$4
			M8 paper	<$0.50

a: Except as noted otherwise, approximate cost per sample analysis in extended use, based on cost of consumable items (excluding original purchase price of the technology).

b: Per sample cost assumes 100 samples can be screened per hydrogen supply, and that refill costs are worst-case $250 per supply (see text).

c: Cost per sample estimated based on original purchase price and number of analyses provided by original materials (consumables not available except as part of kit).

prices of different technologies can be misleading, because many of the technologies as purchased can screen relatively few samples with the original materials. For example, for the technologies in Table 5-7 that rely on color indicating tubes, the purchased technology typically allows screening of between 10 and 40 samples. Testing larger numbers of samples requires obtaining additional tubes, and indeed numerous purchases of additional consumable items were needed to complete the testing reported here. At the lowest extreme in terms of original purchase price are the Safety Solutions HazMat Smart Strip and HazMat Smart M8 at $20 and $6, respectively. However these indicator card technologies are purchased one at a time, so only a single sample screening is obtained for that price. At the other extreme, the RAE MultiRAE Plus, Smiths Detection APD2000, and Proengin AP2C detectors are capable of screening large numbers of samples without frequent replacement of consumables.

Table 5-7 shows that for many of the color tubes, tickets, and cards tested, per-sample costs in long-term use are typically $4 to $20, with some variation depending on the CWA in question. The various indicating papers (M8, M9, and 3-way) from multiple vendors provide the lowest per-sample cost, estimated at $0.50 or less. These technologies are purchased as packets or rolls of paper, and can be cut into small pieces for use without affecting their indicating properties. The Agentase CAD Kit is relatively expensive, at approximately $47 per single-use indicating pen.

The long term per-sample costs of the RAE MultiRAE Plus, Proengin AP2C, and Smiths Detection APD2000 are relatively low, but are also less well defined. For the MultiRAE Plus, the primary expendable cost will be replacement of batteries, but battery life was not assessed in this test. This cost would probably equate to pennies per sample in continuous use. Ultimately, however, the per-sample cost of the MultiRAE Plus may not matter to a decision-maker, as this device was ineffective at detecting vapor phase CWAs.

The Proengin AP2C uses low-pressure hydrogen supplies that are designed to last for 12 hours of continuous use. Supply life was not tested in this program but this life seems reasonable based on the experience in testing the instrument. The Proengin AP2C is designed to be turned off whenever sample screening is not in progress, so the 12-hour supply life can equate to substantially longer periods of use depending on the frequency of sample screening. An indicator on the instrument shows the status of the hydrogen supply. Two fully charged hydrogen supplies are provided in the Proengin AP2C package. These supplies can be refilled by Proengin at a cost of $25 each, plus a charge of $225 for shipping of 1 to 10 supplies at a time to and from Proengin's office in Fort Lauderdale, Florida. Purchase of single, new, fully charged hydrogen supplies, separate from purchase of the detector, costs $488 each. A refilling bench that allows the user to recharge the supplies from a high pressure cylinder of hydrogen is also available for approximately $65,000. The Proengin AP2C also uses batteries, however the cost of battery replacement is likely trivial compared to the cost of replacing the hydrogen supply.

The Smiths Detection APD2000 will also require periodic battery replacement, and rarely the replacement of the surrogate chemical source that is used as a check of proper instrument operation. Costs for these items in long-term use should be small.

6.0 Performance Summary

The ideal characteristics of a CWA screening technology for use in the AHRF include accurate detection of CWAs; absence of false positive and negative responses; absence of temperature, RH, or interferent effects; a rapid and simple sample screening process; and low initial and operating costs. The testing reported here was designed to evaluate the screening technologies on each of these characteristics, and that purpose was accomplished. However, the limitations of this evaluation relative to screening samples in the AHRF should also be noted. This evaluation addressed a wide variety of screening technologies, and focused on the relative performance of those technologies for use in the AHRF, rather than on in-depth investigation of any single technology. Similarly, testing of vendor performance claims was not an objective of the evaluation. For example, determination of the detection limits of the screening technologies was specifically not a goal of this evaluation. Rather, the challenge CWA concentrations were chosen based on health risk information and the desire to protect AHRF staff, and the ability to detect the
presence of CWAs at those levels was assessed regardless of vendor claims about detection limits. Also, test conditions in this evaluation were intended to represent those under which the screening technologies might actually be used in the AHRF, but those actual screening conditions are not completely known at this time. Thus the sample matrices, temperature and RH ranges, and interferences used may not fully address the reality of AHRF operations. This evaluation also focused on relatively inexpensive technologies suitable for screening large numbers of samples. Other, far more expensive, technologies exist that might prove useful in some aspects of AHRF operations. However, this evaluation tested each technology in realistic use by a skilled practitioner, in a manner that closely represents how the technology would be used under the AHRF screening protocol (Figure 1-1). As a result, the results summarized below represent a valuable assessment of the usefulness of each technology for AHRF screening.

Regarding accuracy for screening vapor phase CWAs, five of the 10 technologies tested with GB correctly detected that agent, and four of the eight technologies tested with HD correctly detected that agent. The five screening technologies that accurately detected GB vapor (Anachemia C2 Color Ticket, Draeger Civil Defense Kit, MSA Single CWA Kit, Proengin AP2C, and Truetech M18A3 Color Ticket) did so even in the presence of the hydrocarbon interferent mixture, and at Low and High temperature and RH conditions. Of the four screening technologies that accurately detected HD vapor at the base test conditions (Anachemia C2 Color Tubes, Draeger Civil Defense Kit, Nextteq Civil Defense Kit, and Smiths Detection APD2000), only the Draeger Civil Defense Kit and Nextteq Civil Defense Kit also did so at all temperature/RH conditions and with the interferent mixture present.

Accurate detection of CWAs in water samples was limited to four technologies (out of 11 tested) that were able to detect one or more CWAs. The Severn Trent Eclox Pesticide Strip and Truetech M272 Water Kit color ticket, both of which use acetylcholinesterase inhibition as their detection principle, correctly detected GB and VX in water (both without and with diesel fuel added as an interferent). The Proengin AP2C correctly detected GB in all samples, but did not respond to VX, and responded strongly to HD only when the diesel fuel interferent was present. Without the diesel fuel present, the AP2C gave very brief positive responses in two of three HD challenges. The Nextteq Civil Defense Kit M8 paper responded to VX challenge samples with a light yellow color indicating GB, but did not respond to GB challenges, and showed positive responses to HD in only two of three challenge samples. The other test papers (M8, M9, and 3-way) were not able to detect the CWAs at the challenge concentrations used in water samples in this evaluation.

Accuracy in detecting VX on test coupon surfaces was high, with all nine of the tested technologies correctly detecting VX even at High and Low temperature and RH conditions, and with diesel fuel present on the surface as an interferent. Among those nine technologies were the various test papers (M8, M9, and 3-way).

In terms of false positive responses, two color tube technologies (the Draeger Civil Defense Kit and MSA Single CWA Sampler Kit) each showed three faint positive responses when sampling the hydrocarbon interferent mixture in otherwise clean air during GB vapor testing. The Smiths Detection APD2000 gave one false positive response with that same interferent in HD vapor testing. The Anachemia C2 Color Tubes showed faint positive responses with blank challenges at both Low and High temperature/RH conditions (the same faint positive responses were also observed with the HD challenges at those conditions). None of the tested technologies produced any false positive responses in testing with CWAs in water samples. In surface testing, the Proengin AP2C gave two false positive responses when sampling blank coupons at the High temperature and RH condition. Those responses appeared to be a memory effect after strong positive responses were observed to the challenge (spiked) coupons at that condition.

False negatives were observed with several screening technologies in both the CWA vapor and liquid sample testing, in the inability of the technologies to detect a CWA under the base test conditions. False negatives were also observed in a few cases when testing with an interferent, or at Low or High temperature/RH conditions. Those occurrences are described in the next paragraph. A few technologies showed false negative responses in CWA vapor testing even though the GB or HD challenge concentration was equal to or higher than the stated detection limit of the technology.

Most screening technologies showed no effect from the interferents used in the evaluation. However, the Anachemia C2 Color Tubes and Smiths Detection APD2000 both were unable to detect HD vapor when the hydrocarbon interferent mixture was present, though they accurately detected HD in the absence of that interferent. Diesel fuel added as an interferent reduced the ability of the Nextteq Civil Defense Kit to detect VX and HD in water samples, but in contrast the Proengin AP2C detected HD in water more accurately with diesel fuel present than without it. Temperature and RH effects were also minimal; the only effect was that the Anachemia C2 Color Tubes showed faint positive responses with all blank and challenge samples in HD vapor testing at both the Low and High temperature/RH conditions.

The speed and simplicity of the screening process varied widely among the tested technologies, and the easiest technologies to use were not necessarily the most accurate in CWA screening. The vapor detection technologies based on color indicating tubes were simple to use in principle, but differed in the time and difficulty of obtaining the sample. With such technologies, the number of manual pump strokes required ranged widely, and the manual effort needed for those technologies requiring multiple pump strokes was sometimes excessive even when screening small numbers of samples as in this test. The electric air sampling pump in the Nextteq Civil Defense Kit greatly reduced the physical effort needed but still required a few minutes to draw the required volume. Use of color indicating tubes that require the minimum sample volume would seem preferable for use in the AHRF, and use of an electrical sampling pump might be helpful even then, if large numbers of samples are to be screened. The three real-time analyzers tested (RAE MultiRAE Plus, Proengin AP2C, and Smiths Detection APD2000) provided easy and rapid sample screening for CWA vapors, though with differing levels of success in CWA detection. The HazMat Smart Strip was the simplest technology to use, requiring only removal of a protective film to expose the indicating patches on the card. However, this technology did not respond to GB vapor.

In terms of the speed and simplicity of liquid and surface sample screening, the M8, M9, and 3-way indicating papers were especially easy to use. The Severn Trent Pesticide Strips and Truetech M272 Water Kit color tickets were also relatively simple, and the screening of water and surface samples with the Proengin AP2C was also relatively rapid, because of the simplicity of using the "scraper" attachment and desorbing the sample into the instrument inlet.

The applicability of a technology to screen for multiple CWAs at once is an important component of the speed of analysis. Technologies using multiple color indicating tubes at once (e.g., the Draeger Civil Defense Kit and Nextteq Civil Defense Kit) can provide this capability. On the opposite end of the complexity spectrum, the Proengin AP2C provided multi-CWA capability, and was applicable to vapor, liquid, and surface samples.

The initial cost of the tested technologies varied substantially, with most technology purchase costs ranging from a few hundred to a few thousand dollars. The Proengin AP2C was most expensive at a discounted cost of nearly $16,000. However, when considering long-term use of the technologies in the AHRF, the per-sample CWA screening costs were similar across many different technologies, i.e., typically ranging from $4 to $20 per sample. The simple test papers were the least expensive, with screening costs estimated at less than $0.50 per sample.

7.0 References

1. Draft Interim All Hazards Receipt Facility Protocol, Standard Operating Procedures, (Guidance) – Working Draft, U.S. Environmental Protection Agency, National Homeland Security Research Center, September 5, 2006

2. Draft Interim All Hazards Receipt Facility (AHRF) Protocol, Quick Reference Guide – Working Draft, U.S. Environmental Protection Agency, National Homeland Security Research Center, August 31, 2006

3. Testing of Screening Technologies for Detection of Toxic Industrial Chemicals in All Hazards Receipt Facilities, final report for All Hazards Receipt Facility Monitoring and Detection Technology Testing and Evaluation, Contract GS23F0011L-3, Task Order 1119, Battelle, Columbus, Ohio, March 2007.

4. Test/QA Plan for Evaluation of Sample Screening Technologies for the All Hazards Receipt Facility, Version 1, Battelle, Columbus, Ohio, May 26, 2006.

5. Quality Management Plan for the Technology Testing and Evaluation Program, Version 2, Battelle, Columbus, Ohio, January 2006.

6. Acute Exposure Guideline Levels published by the National Research Council, National Academy of Sciences, and available from the U.S. Environmental Protection Agency at http://www.epa.gov/oppt/aegl/sitemap.htm.

7. Information on the chemistry of CWAs compiled by Noblis Inc., and available at http://www.noblis.org/ChemistryOfLethalChemicalWarfareCWAgents.htm.

APPENDIX A

RESULTS OF TESTING WITH VAPOR PHASE CHEMICAL WARFARE AGENTS

CWA Vapor Challenge Results Summary

Technology	Chemical	Temp	RH	Interferent	Type of test	Result	Positive?	Count of Result
Anachemia C2 Color Ticket								
	GB	Medium	Medium	none	Blank	blue	No	6
	GB	Medium	Medium	none	Challenge	white	Yes	6
	GB	Medium	Medium	Gas exhaust	Blank	blue	No	3
	GB	Medium	Medium	Gas exhaust	Challenge	white	Yes	3
	GB	Low	Low	none	Blank	very light	No	1
	GB	Low	Low	none	Blank	yellow tinge	No	2
	GB	Low	Low	none	Challenge	white	Yes	3
	GB	High	High	none	Blank	blue	No	3
	GB	High	High	none	Challenge	white	Yes	3
Anachemia C2 Color Tubes								
	HD	Medium	Medium	none	Blank	negative	No	3
	HD	Medium	Medium	none	Challenge	blue	Yes	3
	HD	Medium	Medium	Gas exhaust	Blank	negative	No	3
	HD	Medium	Medium	Gas exhaust	Challenge	negative	No	3
	HD	Low	Low	none	Blank	blue	Yes	3
	HD	Low	Low	none	Challenge	blue	Yes	3
	HD	High	High	none	Blank	blue	Yes	3
	HD	High	High	none	Challenge	blue	Yes	3
Anachemia CM256A1								
	GB	Medium	Medium	none	Blank	negative	No	6
	GB	Medium	Medium	none	Challenge	negative	No	6
	HD	Medium	Medium	none	Blank	negative	No	3
	HD	Medium	Medium	none	Challenge	negative	No	3

Technology	Chemical	Temp	RH	Interferent	Type of test	Result	Positive?	Count of Result
Draeger Civil Defense Kit								
	GB	Medium	Medium	none	Blank	negative	No	6
	GB	Medium	Medium	none	Challenge	red	Yes	6
	GB	Medium	Medium	Gas exhaust	Blank	light pink	Yes	3
	GB	Medium	Medium	Gas exhaust	Challenge	dark red	Yes	3
	GB	Low	Low	none	Blank	negative	No	3
	GB	Low	Low	none	Challenge	red	Yes	3
	GB	High	High	none	Blank	negative	No	3
	GB	High	High	none	Challenge	red	Yes	3
	HD	Medium	Medium	none	Blank	negative	No	3
	HD	Medium	Medium	none	Challenge	orange	Yes	3
	HD	Medium	Medium	Gas exhaust	Blank	negative	No	3
	HD	Medium	Medium	Gas exhaust	Challenge	orange	Yes	3
	HD	Low	Low	none	Blank	negative	No	3
	HD	Low	Low	none	Challenge	orange	Yes	3
	HD	High	High	none	Blank	negative	No	3
	HD	High	High	none	Challenge	orange	Yes	3
MSA CWA Sampler Kit								
	GB	Medium	Medium	none	Blank	negative	No	6
	GB	Medium	Medium	none	Challenge	yellow	Yes	6

Technology	Chemical	Temp	RH	Interferent	Type of test	Result	Positive?	Count of Result
	GB	Medium	Medium	Gas exhaust	Blank	faint yellow	No	3
	GB	Medium	Medium	Gas exhaust	Challenge	yellow	Yes	3
	GB	Low	Low	none	Blank	negative	No	3
	GB	Low	Low	none	Challenge	yellow	Yes	3
	GB	High	High	none	Blank	negative	No	3
	GB	High	High	none	Challenge	yellow	Yes	3
	HD	Medium	Medium	none	Blank	negative	No	3
	HD	Medium	Medium	none	Challenge	negative	No	3
Nextteq Civil Defense Kit								
	GB	Medium	Medium	none	Blank	negative	No	6
	GB	Medium	Medium	none	Challenge	negative	No	6
	HD	Medium	Medium	none	Blank	negative	No	3
	HD	Medium	Medium	none	Challenge	orange	Yes	3
	HD	Medium	Medium	Gas exhaust	Blank	negative	No	3
	HD	Medium	Medium	Gas exhaust	Challenge	orange	Yes	3
	HD	Low	Low	none	Blank	negative	No	3
	HD	Low	Low	none	Challenge	orange	Yes	3
	HD	High	High	none	Blank	negative	No	3
	HD	High	High	none	Challenge	orange	Yes	3
Proengin AP2C								
	GB	Medium	Medium	none	Blank	negative	No	6
	GB	Medium	Medium	none	Challenge	positive	Yes	6
	GB	Medium	Medium	Gas exhaust	Blank	negative	No	1
	GB	Medium	Medium	Gas exhaust	Blank	CH	No	2
	GB	Medium	Medium	Gas exhaust	Challenge	2 bar GB	Yes	3

Technology	Chemical	Temp	RH	Interferent	Type of test	Result	Positive?	Count of Result
	GB	Low	Low	none	Blank	negative	No	3
	GB	Low	Low	none	Challenge	1 bar GB	Yes	3
	GB	High	High	none	Blank	no bars	No	3
	GB	High	High	none	Challenge	1 bar G,V	Yes	3
	HD	Medium	Medium	none	Blank	negative	No	3
	HD	Medium	Medium	none	Challenge	negative	No	3
RAE systems MultiRAE Plus								
	GB	Medium	Medium	none	Blank	negative	No	6
	GB	Medium	Medium	none	Challenge	negative	No	6
	HD	Medium	Medium	none	Blank	negative	No	3
	HD	Medium	Medium	none	Challenge	negative	No	3
Safety Solutions HazMat Smart Strip								
	GB	Medium	Medium	none	Blank	negative	No	3
	GB	Medium	Medium	none	Challenge	negative	No	3
	HD	Medium	Medium	none	Blank	negative	No	3
	HD	Medium	Medium	none	Challenge	negative	No	3
Smiths APD2000								
	GB	Medium	Medium	none	Blank	negative	No	3
	GB	Medium	Medium	none	Challenge	negative	No	3
	HD	Medium	Medium	none	Blank	negative	No	6
	HD	Medium	Medium	none	Challenge	blister	Yes	6
	HD	Medium	Medium	Gas exhaust	Blank	blister	Yes	1
	HD	Medium	Medium	Gas exhaust	Blank	negative	No	2
	HD	Medium	Medium	Gas exhaust	Challenge	negative	No	3

Technology	*Chemical*	*Temp*	*RH*	*Interferent*	*Type of test*	*Result*	*Positive?*	*Count of Result*
	HD	Low	Low	none	Blank	negative	No	3
	HD	Low	Low	none	Challenge	blister	Yes	3
	HD	High	High	none	Blank	negative	No	3
	HD	High	High	none	Challenge	blister	Yes	3
Truetech M18A3 Color Ticket								
	GB	Medium	Medium	none	Blank	blue	No	6
	GB	Medium	Medium	none	Challenge	white	Yes	6
	GB	Medium	Medium	Gas exhaust	Blank	blue	No	3
	GB	Medium	Medium	Gas exhaust	Challenge	white	Yes	3
	GB	Low	Low	none	Blank	blue	No	3
	GB	Low	Low	none	Challenge	white	Yes	3
	GB	High	High	none	Blank	negative	No	3
	GB	High	High	none	Challenge	positive	Yes	3

APPENDIX B

RESULTS OF TESTING WITH CHEMICAL WARFARE AGENTS IN LIQUID SAMPLES

CWA Liquid Challenge Results Summary

Technology	Solvent used	Interferent	Type of Test	Response	Positive?	Count of Response
Anachemia C2 3-way paper						
	IPA	none	Blank	none	No	3
	IPA	none	GB	none	No	3
	IPA	none	HD	none	No	3
	IPA	none	VX	none	No	3
	water	none	Blank	none	No	3
	water	none	GB	none	No	3
	water	none	HD	none	No	3
	water	none	VX	none	No	3
Anachemia CM256A1 3-way paper						
	IPA	none	Blank	none	No	3
	IPA	none	GB	none	No	3
	IPA	none	HD	none	No	3
	IPA	none	VX	none	No	3
	water	none	Blank	none	No	3
	water	none	GB	none	No	3
	water	none	HD	none	No	3
	water	none	VX	none	No	3
Nextteq CD kit 3-way paper						
	IPA	none	Blank	none	No	3
	IPA	none	GB	none	No	3

Technology	Solvent used	Interferent	Type of Test	Response	Positive?	Count of Response
	IPA	none	HD	none	No	3
	IPA	none	VX	none	No	3
	water	none	Blank	none	No	3
	water	none	GB	none	No	3
	water	none	HD	none	No	3
	water	none	VX	none	No	3
Nextteq CD kit M8 paper						
	IPA	none	Blank	none	No	3
	IPA	none	GB	none	No	3
	IPA	none	HD	none	No	3
	IPA	none	VX	none	No	3
	water	none	Blank	none	No	3
	water	none	GB	none	No	3
	water	none	HD	none	No	1
	water	none	HD	red dots	Yes	2
	water	none	VX	light yellow	Yes	3
	water	Diesel fuel	Blank	none	No	3
	water	Diesel fuel	HD	none	No	3
	water	Diesel fuel	VX	light yellow	Yes	2
	water	Diesel fuel	VX	none	No	1
Nextteq CD kit M9 paper						
	IPA	none	Blank	red	Yes	3
	IPA	none	GB	red	Yes	3

Technology	Solvent used	Interferent	Type of Test	Response	Positive?	Count of Response
	IPA	none	HD	red	Yes	3
	IPA	none	VX	red	Yes	3
	water	none	Blank	none	No	3
	water	none	GB	none	No	3
	water	none	HD	none	No	3
	water	none	VX	none	No	3
Proengin AP2C						
	IPA	none	Blank	red P/HNO/As/S	No	1
	IPA	none	Blank	red P/HNO/As/S; 3 bar HD/HL	No	2
	water	Diesel fuel	Blank	none	No	3
	water	Diesel fuel	GB	3 bars G/V	Yes	3
	water	Diesel fuel	HD	4 bars HD/HL	Yes	3
	water	Diesel fuel	VX	CH	No	1
	water	Diesel fuel	VX	none	No	2
	water	none	Blank	none	No	3
	water	none	GB	3 bar G/V	Yes	1
	water	none	GB	4 bar G/V; 1 bar HD/HL	Yes	1
	water	none	GB	5 bar G/V; 3 bar HD/HL	Yes	1
	water	none	HD	1 bar HD/HL	Yes	2
	water	none	HD	none	No	1
	water	none	VX	none	No	3
Safety Solutions HazMat Smart M8						
	IPA	none	Blank	none	No	3

Technology	Solvent used	Interferent	Type of Test	Response	Positive?	Count of Response
	IPA	none	GB	none	No	3
	IPA	none	HD	none	No	3
	IPA	none	VX	none	No	3
	water	none	Blank	none	No	3
	water	none	GB	none	No	3
	water	none	HD	none	No	3
	water	none	VX	none	No	3
Safety Solutions Hazmat Smart Strip						
	IPA	none	Blank	none	No	3
	IPA	none	GB	none	No	3
	IPA	none	VX	none	No	3
	water	none	Blank	none	No	3
	water	none	GB	none	No	3
	water	none	VX	none	No	3
Severn Trent Eclox Kit						
	IPA	none	Blank	pink&white	Yes	2
	IPA	none	Blank	white&white	Yes	1
	IPA	none	GB	pink&white	Yes	3
	IPA	none	VX	pink&white	Yes	1
	IPA	none	VX	white&white	Yes	2
	water	none	Blank	blue	No	3
	water	none	GB	white	Yes	3
	water	none	VX	white	Yes	3

Technology	Solvent used	Interferent	Type of Test	Response	Positive?	Count of Response
	water	Diesel fuel	Blank	blue	No	3
	water	Diesel fuel	GB	white	Yes	3
	water	Diesel fuel	VX	white	Yes	3
Truetech M18A3 M8 paper						
	IPA	none	Blank	none	No	3
	IPA	none	GB	none	No	3
	IPA	none	HD	none	No	3
	IPA	none	VX	none	No	3
	water	none	Blank	none	No	3
	water	none	GB	none	No	3
	water	none	HD	none	No	3
	water	none	VX	none	No	3
Truetech M272 Water Kit						
	IPA	none	Blank	pinkish&white	Yes	3
	IPA	none	GB	pinkish&white	Yes	3
	IPA	none	VX	pinkish&white	Yes	3
	water	none	Blank	blue	No	3
	water	none	GB	white	Yes	3
	water	none	VX	white	Yes	3
	water	Diesel fuel	Blank	blue	No	3
	water	Diesel fuel	GB	white	Yes	3
	water	Diesel fuel	VX	white	Yes	3

APPENDIX C

RESULTS OF TESTING WITH CHEMICAL WARFARE AGENTS ON SURFACE SAMPLES

CWA Surface Challenge Results Summary

Technology	Chemical	Temp	RH	Interferent	Type of Test	Result	Positive?	Count of Result
Agentase CAD Kit								
	VX	Medium	Medium	none	Blank	none	No	3
	VX	Medium	Medium	none	Challenge	pink/lt. purple	Yes	3
	VX	Medium	Medium	Diesel Fuel	Blank	yellow	No	3
	VX	Medium	Medium	Diesel Fuel	Challenge	Pink	Yes	3
	VX	Low	Low	none	Blank	yellow	No	3
	VX	Low	Low	none	Challenge	pink	Yes	3
	VX	High	High	none	Blank	yellow	No	3
	VX	High	High	none	Challenge	redish/purple	Yes	3
Anachemia C2 3-way paper								
	VX	Medium	Medium	none	Blank	none	No	3
	VX	Medium	Medium	none	Challenge	green	Yes	3
	VX	Medium	Medium	Diesel Fuel	Blank	none	No	1
	VX	Medium	Medium	Diesel Fuel	Blank	pink	No	2
	VX	Medium	Medium	Diesel Fuel	Challenge	green	Yes	3
	VX	Low	Low	none	Blank	none	No	3
	VX	Low	Low	none	Challenge	green	Yes	3
	VX	High	High	none	Blank	none	No	3
	VX	High	High	none	Challenge	green	Yes	3
Anachemia CM256A1 3-way paper								
	VX	Medium	Medium	none	Blank	none	No	3
	VX	Medium	Medium	none	Challenge	green	Yes	3

Technology	Chemical	Temp	RH	Interferent	Type of Test	Result	Positive?	Count of Result
	VX	Medium	Medium	Diesel Fuel	Blank	red	No	3
	VX	Medium	Medium	Diesel Fuel	Challenge	green and red	Yes	3
	VX	Low	Low	none	Blank	none	No	3
	VX	Low	Low	none	Challenge	green	Yes	3
	VX	High	High	none	Blank	none	No	3
	VX	High	High	none	Challenge	green	Yes	3
Nextteq 3-way paper								
	VX	Medium	Medium	none	Blank	none	No	3
	VX	Medium	Medium	none	Challenge	green	Yes	3
	VX	Medium	Medium	Diesel Fuel	Blank	pink	No	3
	VX	Medium	Medium	Diesel Fuel	Challenge	green and pink	Yes	3
	VX	Low	Low	none	Blank	none	No	3
	VX	Low	Low	none	Challenge	green	Yes	3
	VX	High	High	none	Blank	none	No	3
	VX	High	High	none	Challenge	green	Yes	3
Nextteq M8 paper								
	VX	Medium	Medium	none	Blank	none	No	3
	VX	Medium	Medium	none	Challenge	green	Yes	3
	VX	Medium	Medium	Diesel Fuel	Blank	pink	No	3
	VX	Medium	Medium	Diesel Fuel	Challenge	green and pink	Yes	3
	VX	Low	Low	none	Blank	none	No	3
	VX	Low	Low	none	Challenge	green	Yes	3
	VX	High	High	none	Blank	none	No	3
	VX	High	High	none	Challenge	green	Yes	3
Nextteq M9 paper								
	VX	Medium	Medium	none	Blank	none	No	3
	VX	Medium	Medium	none	Challenge	red	Yes	3

Technology	Chemical	Temp	RH	Interferent	Type of Test	Result	Positive?	Count of Result
	VX	Medium	Medium	Diesel Fuel	Blank	none	No	3
	VX	Medium	Medium	Diesel Fuel	Challenge	red	Yes	3
	VX	Low	Low	none	Blank	none	No	3
	VX	Low	Low	none	Challenge	red	Yes	3
	VX	High	High	none	Blank	none	No	3
	VX	High	High	none	Challenge	red	Yes	3
Proengin AP2C								
	VX	Medium	Medium	none	Blank	none	No	3
	VX	Medium	Medium	none	Challenge	4 bars G,V	Yes	1
	VX	Medium	Medium	none	Challenge	3 bars G,V	Yes	2
	VX	Medium	Medium	Diesel Fuel	Blank	CH	No	3
	VX	Medium	Medium	Diesel Fuel	Challenge	3 bars G,V	Yes	2
	VX	Medium	Medium	Diesel Fuel	Challenge	4 bars G,V	Yes	1
	VX	Low	Low	none	Blank	none	No	3
	VX	Low	Low	none	Challenge	3 bars G,V	Yes	1
	VX	Low	Low	none	Challenge	4 bars G,V	Yes	1
	VX	Low	Low	none	Challenge	5 bars G,V	Yes	1
	VX	High	High	none	Blank	flashed CH	No	1
	VX	High	High	none	Blank	1 bar G,V	Yes	1
	VX	High	High	none	Blank	3 bars HD,HL	Yes	1
	VX	High	High	none	Challenge	5 red bars G,V	Yes	1
	VX	High	High	none	Challenge	1 red bar G,V	Yes	2
Safety Solutions Hazmat Smart M8								
	VX	Medium	Medium	none	Blank	none	No	3
	VX	Medium	Medium	none	Challenge	green	Yes	3

Technology	Chemical	Temp	RH	Interferent	Type of Test	Result	Positive?	Count of Result
	VX	Medium	Medium	Diesel Fuel	Blank	slight pink	No	3
	VX	Medium	Medium	Diesel Fuel	Challenge	dark green	Yes	1
	VX	Medium	Medium	Diesel Fuel	Challenge	green	Yes	1
	VX	Medium	Medium	Diesel Fuel	Challenge	green and pink	Yes	1
	VX	Low	Low	none	Blank	none	No	3
	VX	Low	Low	none	Challenge	green	Yes	3
	VX	High	High	none	Blank	none	No	3
	VX	High	High	none	Challenge	green	Yes	3
Truetech M18A3 M8 paper								
	VX	Medium	Medium	none	Blank	none	No	3
	VX	Medium	Medium	none	Challenge	green	Yes	3
	VX	Medium	Medium	Diesel Fuel	Blank	none	No	2
	VX	Medium	Medium	Diesel Fuel	Blank	very slight pink	No	1
	VX	Medium	Medium	Diesel Fuel	Challenge	green	Yes	2
	VX	Medium	Medium	Diesel Fuel	Challenge	green and pink	Yes	1
	VX	Low	Low	none	Blank	none	No	3
	VX	Low	Low	none	Challenge	green	Yes	3
	VX	High	High	none	Blank	none	No	3
	VX	High	High	none	Challenge	green	Yes	3

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